



THE HISTORY OF SCIENCE AND TECHNOLOGY

*A Browser's Guide to
the Great Discoveries, Inventions,
and the People Who Made Them from the Dawn of Time to Today*



BRYAN BUNCH with ALEXANDER HELLEMANS

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Introduction

Welcome to a complicated book that I think will be easy to read and use.

Most histories of science or technology present a highly selected story of the most important discoveries. *The History of Science and Technology* takes a different approach. While there are narrative accounts of more than a hundred different topics — these are the short essays that have gray backgrounds to distinguish them from other elements of the book — the main body of the book is a chronicle of virtually everything that has happened in science and technology, including false steps and ignored precursors. Cross references, labeled *See also*, direct the reader to the related material that begins, continues, or concludes a line of investigation. Thus, there are thousands of separate histories embedded in the chronicle section. A comprehensive index provides yet another way to follow a particular line of development.

The History of Science and Technology is separated into ten chapters, each representing a major division of the history of science and technology. The introductions to these chapters provide a more conventional history, with the emphasis on the character and philosophy of the period, the new ideas or methods that emerged during the period, and the major advances in each branch of science or technology.

Throughout the chronicle an effort has been made to do more than simply list the achievements, which might be recognized by a scientist or mathematician but not by the ordinary reader.

Instead, chronicle entries are often expanded to give a very brief précis of the meaning of terms or the impact of a discovery on science or society.

As a part of the chronicle, brief biographies, set off in boxes, are provided for the most important scientists or inventors. These biographies are placed near the first mentioned achievement of the scientist or inventor and provide information on the birth and death places and dates within the box. Most other scientists or inventors have birth and death information shown within square brackets at the first mention.

The square brackets for birth and death information are one of several typographical devices used throughout the book. Another is the use of place names in parentheses that provide the modern names for nations and sometimes cities. For example, the city known as Königsberg during the 19th century is further identified by its current name as (Kaliningrad, Russia) or an ancient city such as Nineveh is identified by the modern name of the country where its ruins are found, (Iraq). Many book titles or words are given in their original language but translated in a combination of parentheses with quotations marks, as for example, Galileo's *Dialogo sopra i due massimi sistemi del mondo, Tolemaico e Copernico* ("dialogue concerning the two chief world systems, Ptolemaic and Copernican"). Dates are given throughout in terms of CE ("common era") and BCE ("before common era"). The dating system is explained more fully on page 4.

The History of Science and Technology is based on two earlier books: *Timetables of Science* by Alexander Hellemans and Bryan Bunch; and *Timetables of Technology* by Bryan Bunch and Alexander Hellemans. Many of the essays, portions of the chapter introductions, and chronicle entries were originally written by Hellemans for these books. Hellemans also contributed some new chronicle entries and essays to this book. But the present selection and arrangement of material as well as all editing is entirely my responsibility, including of course any errors of fact or interpretation.

I want to thank especially my agent, John W. Wright, who has not only supported this book and its predecessors, but contributed to the structures that make these books work in their own rather unusual ways, and also Gordon Hardy, my editor at Houghton Mifflin, for his patience during a long production process. Thanks also go to my friends Jenny Tesar, whose help with the history of biology was invaluable, and the artist James Koran Davis, who not only concerned himself with the progress of the book on a regular basis but also contributed a number of drawings and photographs that make it possible to visualize some of the ideas and inventions. My wife Mary did a lot of everything to make this project happen, from research to reading to indexing, and at the same time put up with a husband who spent an inordinate amount of time shut away with the history of science and technology.

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Science and Technology before Scientists: through 599 BCE

Although early humans and their ancestors understood many natural laws and developed skills for making useful tools, no one person could be described as the first scientist. Nameless Egyptians, Sumerians, Chinese, Maya, and others worked out mathematical rules, cured illnesses, built great structures, created new materials, and learned how to read the stars and planets — but their successes were largely a collection of skills, rather than a science. Science as an organized body of thought is usually identified with the Ionian school of Greek philosophers (about 600 BCE) or later, perhaps as late as the Scientific Revolution of the 17th century. The Ionian philosophers made a serious effort to develop a rational basis for the universe, although few of those early thinkers could be called scientists or mathematicians in the modern sense of the word.

Advances in knowledge, skills, and technology, however, had been part of human history long before our ancestors were fully human. We begin by considering the arts, inventions, and understandings of this early period, which might be classified as crafts or technology.

The Stone Ages

Stone tools have long been the first recognized technology. It is almost certain that wooden tools preceded stone by millions of years, but wood survives only in exceptional circumstances. Therefore, we must begin with the stone tools first found in the Olduvai Gorge in Tanzania by Louis and Mary

Leakey and others, and since found elsewhere in Africa as well. It is customary to think that those tools were made by one of our direct ancestors, perhaps *Homo habilis* or *H. rudolfensis* 2,500,000 years ago. Despite this common assumption, some evidence suggests that the first stone tools were made by those early relatives not on the direct line to modern humans, the australopithecines.

The early tools associated with *H. habilis* and *H. rudolfensis* were simple broken pebbles. The next technology we know of came after different species emerged, *H. ergaster* and *H. erectus* (1,800,000 years ago). These African and Asian humans greatly improved stone tools by flaking pieces off a core, creating distinctive shapes with only a single cutting edge that we call hand axes (or bifaces) and scrapers or choppers. The hammerstone used to work the other tools could be thought of as the first “machine tool.”

Today we are so accustomed to the idea of a time called the Stone Age that it is easy to forget that the expression was coined less than two centuries ago by Christian Jürgensen Thomsen for a project started in 1816. He divided early artifacts for a museum collection into stone, bronze, and iron. The museum catalog, published in 1836, enshrined the Stone, Bronze, and Iron ages. In 1865 Sir John Lubbock further subdivided the Stone Age into the Old Stone Age and the New Stone Age. After these simple names were translated into the Greek-derived technical terms *Paleolithic* and *Neolithic*, a middle stone age, the *Mesolithic* was added.

The hand axe and scraper set of

tools, or toolkit or industry, continued for more than a million years before a different stone tool emerged. Various types of points, often considered to be spearheads, knives, arrowheads, or teeth (such as saws’ teeth) were devised. They became parts of different toolkits used by different societies of later species, such as *H. heidelbergensis* and *H. neanderthalensis* (600,000 to 30,000 years ago), as well as by our own species, *H. sapiens* (which may be 200,000 years old). Other stone tools from this period included awls or needles as well as burins (engraving tools).

The New Stone Age, or Neolithic, occupies a much shorter time than the Old Stone Age. Various criteria produce different starting dates for the Neolithic, but in terms of the kinds of stone tools manufactured, such as ground stone axe or adze heads and small points called microliths, the period began as early as 20,000 years ago in Europe and ended when metal came into common use, about 5,000 years ago. In other regions, Neolithic technology persisted much later, with some stone tools, such as arrowheads, still in use in the 20th century in a few societies.

Knowledge among hunter-gatherers

The great apes live primarily by foraging, rather than gathering — the difference being that a gatherer brings food picked up in various places back to a central location for consumption or storage whereas a forager eats the food on site. There is no reason to suppose that the earliest hominids were gatherers, but there is some evidence that *H. habilis* and *H. rudolfensis* occupied cer-

Science and Technology before Scientists: through 599 BCE

tain sites, called living floors by paleoanthropologists (scientists who study early hominids, including early *H. sapiens*). Thus, we believe that these early hominids had a lifestyle that is called hunting and gathering, an economy that persists today in a few isolated societies. The hunting part is sometimes questioned. Many anthropologists think that *H. habilis* was largely a scavenger of meat as well as a gatherer of berries, nuts, and roots.

These early hunter-gatherers or scavenger-gatherers are thought to have had skills not much better than those of animals: recognition of the plants that could be eaten and where to find them; the ability to make simple tools for digging roots or scraping meat off bone; and perhaps the wherewithal to manufacture snares for small game. Modern hunter-gatherers know a great deal about everything in the territory they cover, but that does not mean that the much smaller brained *H. habilis* and *H. rudolfensis* were as sophisticated.

Hunting became increasingly important to *H. ergaster* and *H. erectus*. They certainly learned the ways of their prey animals. These people discovered how to control fire and began to build substantial structures with wood posts, although some lived in caves and rock shelters.

The later hunter-gatherers, such as *H. neanderthalensis* (the Neandertals) and *H. sapiens*, progressed in several areas of technology and science while still maintaining a hunter-gatherer lifestyle. Hunting weapons, such as the sling, the bow, the bolo, the fish hook, and the spear thrower, are among the technological innovations of this period. The progress in technology is most clearly seen in the further refinement of stone tools and in the Neolithic use of many other materials. Metal tools were preceded by bone tools, such as needles, that could not have been easily made from stone. Although remains of

more perishable tools are scarce in the archaeological record, there is no doubt that similar progress was being made in tools based on wood or other organic materials. Although most early wooden tools have vanished, some of these inventions can be seen in early drawings or engravings.

There is also some evidence that mathematics and astronomy, subjects that have been linked throughout most of history, were in use by hunter-gatherers. Notches on artifacts have been interpreted as tally marks or counters, as calendars, and as records of the lunar cycle.

Other evidence of astronomy is less certain. Various early structures have been theorized to be observatories, but most of these interpretations are controversial. It seems likely that primitive hunter-gatherers had already detected patterns in the apparent motions of the stars and possibly even in the real motions of the planets through the night sky.

Hunter-gatherers living today have an extensive knowledge of wild animals and plants; there is no reason to expect that this was not also true of Neolithic hunter-gatherers. Botanical taxonomy was undoubtedly accurate, for if it were not, people would not have known which plants were good for food. It is also likely that knowledge of plants whose chemical properties are useful as poisons, dyes, or medicines had its beginnings during the hunter-gatherer period.

Since our ancestors expanded rapidly, such knowledge had to be adjusted for it to be practical worldwide. *H. habilis* and *H. ergaster* were confined to Africa; however, *H. erectus* spread through Asia and *H. Neanderthalensis* through Europe. Around 50,000 to 46,000 years ago, *H. sapiens* reached Australia. A few tens of thousand years later, *H. sapiens* reached the Americas. Each expansion must have presented

the explorers with many taxonomic puzzles: Is this plant that looks like a lentil really a kind of lentil, or is it some poisonous or worthless plant? This led to a steadily expanding grasp of the beginnings of biology.

The Agricultural Revolution and other revolutions

Starting about 10,000 years ago, or near 8000 BCE, people made the major technological advance of domesticating animals and plants. The early part of this Agricultural Revolution, especially in the Middle East, is often called the Neolithic Revolution. Similar agricultural revolutions occurred independently in the Middle East, the Orient, New Guinea, and the Americas. At one time, historians assumed that the Agricultural Revolution was simply a form of progress. This interpretation is now in dispute. Historians currently hypothesize that people knew how to raise crops and keep animals before the Agricultural Revolution, but were reluctant to do so until either rising population or reduced natural food supplies forced them into agriculture. This is partly supported by a rise in population preceding the adoption of agriculture, as indicated in the archaeological record.

Another belief that has largely been discarded is that urban life began as a result of the Agricultural Revolution. Towns were forming before farming became a way of life. The principal purpose of preagricultural settlements was trade. Towns arose at the juncture of trade routes or near supplies of goods that could be traded. Jericho, for example, was founded well before agriculture started.

It is hard to find any evidence of the physical sciences around the time of the Agricultural Revolution except for that dictated by developing technology, such as the introduction of sun-dried bricks

and mortar. Major developments of the period following the Agricultural Revolution were largely in astronomy, mathematics, and technology.

A significant advance toward the end of the Agricultural Revolution, however, was the use of metal instead of stone for tools. Copper was the first metal to be employed and it was in use from as early as 6400 BCE, initiating a period sometimes called the Copper Age. The word "age" in this context is misleading, although it goes back to Thomsen's classification system of Stone, Bronze, and Iron ages. Thomsen's Stone Age covered hundreds of thousands of years (and has since been extended to more than 2,000,000 years), but the Bronze Age, like the Copper Age, lasted only a few thousand years in all. Bronze ruled in Eurasia from about 3000 BCE to 1500 BCE, when iron weapons began to replace those of bronze. Thomsen's Iron Age could be said to be coming to a close about the time that he described his classification system (the Bessemer process for steel making began 20 years after publication of Thomsen's catalog). Although the period from about 6000 BCE to about 1000 BCE is thought of in terms of the three metal ages, it would be equally appropriate to call this the Ceramics Age, since pottery and other ceramics, along with glass, were dominant. For the average person during most of this time, ceramics were far more important than copper, bronze, or iron, which mostly were used by soldiers and specialized technicians, such as carpenters and masons.

Thus, one could speak of the Agricultural Revolution, the Metals Revolution, or the Ceramics Revolution. From other points of view, the same general time period encompassed the Wheel Revolution, giving us the potter's wheel, the wheeled vehicle, and wheels in various devices. In fact, this was also the time of another great advance in transportation — the sail, our first

power source that did not depend on biological input — but the great days of sailing ships were still to come. Finally, this period saw the "dawn of history," for writing was developed.

Civilization

Following the Agricultural Revolution, societies that we recognize as civilizations began to arise. People entered this period as either simple farmers or (in some ways more complicated) hunter-gatherers. Although the vast majority of humans continued to be farmers or hunter-gatherers or both, after civilization started, a significant minority became full-time warriors, traders, merchants, manufacturers, accountants, builders, or rulers. It is thought that the need to maintain stability after the annual flood contributed to a strong central state in Egypt, while centralized control of irrigation projects was the stimulus in Mesopotamia. Less is known about the origins of the other early civilizations: the Indus culture, centered at Harappa and Mohenjo-Daro in the Punjab region of India, and the early Chinese empire. All were flourishing by about 3000 BCE.

Our understanding of these cultures has been influenced by the way we have become aware of them. Egypt, for example, was well known to the Greeks; furthermore, archaeology began there under Napoleon and we have known how to read hieroglyphics since the work of Jean Champollion and Thomas Young in 1822. For these reasons, Egyptian culture is well understood. Many of the Mesopotamian civilizations were somewhat familiar from the Bible's Old Testament, but the ability to read cuneiform and the first excavations in Mesopotamia date back to the 1840s. Civilizations in the Americas were unknown to the Western world until after the 15th century and not studied systematically until the 19th

century. African civilizations, whose ruins were observed in the 19th century, were generally misinterpreted as colonies from Egypt or Arabia until recently. Even more dramatically, the ancient civilization of the Indus River (Pakistan) was not discovered at all until the 1920s. Although Europeans knew of Chinese civilization at the time of the Roman Empire, contact with China was lost during the Middle Ages. Realization of the early Chinese civilization was a slow process that began about 1930; to some extent it is still continuing.

Scholars influenced principally by Mesopotamia and Egypt have defined a civilization as a society that includes towns of at least 5000 people, a written language, and monumental religious works produced in service of a state religion. Yet various civilized societies that we recognize today may fail in any one of these criteria. It is not clear that the Maya had towns, that the Incas or Aztecs had a true written language, or that Chinese monuments were religious. A different definition of civilization (owed to Robert McAdams in 1960) is that a civilized people are divided into classes, society is organized by the state, and labor is specialized into different trades or professions.

Civilization does not seem to have arisen in any one place, although Sumer can lay claim to being the first as far as we know today. The Egyptian civilization that began only a few hundred years later and only a few hundred miles away seems to have come from different sources and to have evolved along its own lines. And certainly the civilizations of the Far East and the Americas are based on a different technology from either of those of the Middle East.

Despite differences in technology or society, all civilizations seem to have arisen politically from similar roots. Villages acquire rulers. Eventually one of

those rulers sets out successfully to rule over the ethnically similar villages in a larger region, effectively becoming a king, whatever the ruler may be called. By a similar process, one of the kings extends sway over a larger region, now encompassing ethnically dissimilar peoples, resulting in an empire. The empire lasts for a time and then disintegrates under pressure from outside or as a result of bad management, often both.

This general pattern has some direct effects on the type of technology possible. Kings and emperors can order large numbers of people to work together on projects. Even without advances in tools or materials, construction projects — pyramids, temples, canals, roads, and so forth — can be accomplished that would be difficult without unified control. Where we observe the construction of large projects without the obvious presence of kings, we suspect that either the kings were present and failed to leave a record or that religious leaders were able to command laborers for the building of monuments. It is hard to picture large numbers of people digging or moving large rocks without some central direction.

The process of forming kingdoms and empires involves warfare in nearly all cases. Thus, military technology is often at the forefront of change. War chariots preceded carts used for hauling goods by hundreds of years. Copper, bronze, and iron were employed in battle axes and arrowheads well before they became common as the tips of plows or in needles.

A note on dating

In this period, only a few events can be dated exactly as to year. For the most part, dates that are given in even millions, thousands, or hundreds of years are approximations — if a known date is specifically an even hundred, such as 300 BCE, that is noted in the entry.

The best true dates for the period, in general, are Egyptian. The Chinese tradition has many specific dates, but scholars think that these are based more upon legends than reality for this early part of Chinese history.

This book uses the convention, becoming more common worldwide, of CE, which stands for “common era,” to describe dates that in the Christian system are labeled AD. Similarly, dates that in the Christian system are labeled BC are here labeled BCE for “before common era.” In some cases, when discussing long ago events that are only approximately dated, the abbreviation BP for “before present” is used.

The present tense is always used in this volume’s chronicle for events that occur on the identified date, while past or future tense is used for events earlier or following that date. Thus, an entry for 1876 CE could read “Alexander Graham Bell invents the telephone. He had transmitted sound over wires the year before. The first telephone exchange will begin operation in 1878.”

Major advances

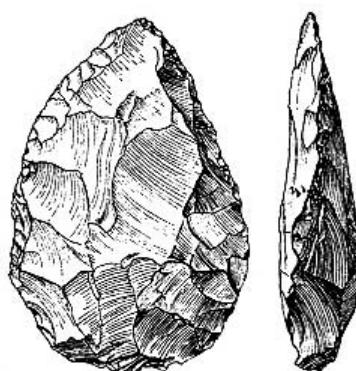
ANTHROPOLOGY Anthropology as a science developed much later than during this period, but we include under the anthropology heading in this chapter’s chronicle information established by physical anthropologists regarding the species involved in the technological issues of this period.

We, our direct ancestors, and their cousins are termed *hominids*. About the time that tool making began, in addition to our ancestors, hominids included the australopithecines, now grouped into two genera, *Australopithecus* and *Paranthropus*. It is thought that these australopithecines had too little brain power to make tools, but their brains were about the same size as those of modern chimpanzees who, we now know, do make simple tools. Brain size

is relevant because the first recognizable manufactured tools, known as pebble or Oldowan tools, are found at sites that include both *Paranthropus* (=*Australopithecus*) *robustus* and *H. habilis*. While we assume that our somewhat larger brained direct ancestor chipped and used those first recognizable stone tools, we cannot be certain that our cousin was not involved. The average australopithecine brain was about 430 cm³ (26 cu in.) although that of the australopithecine *P. robustus* was about a hundred cubic centimeters more. The brain of the first member of the genus *Homo*, *H. habilis* or perhaps *H. rudolfensis*, took a giant leap forward to 750 cm³ (46 cu in.). A look at the actual data shows a more gradual progression from *P. robustus* with a maximum brain of about 550 cm³ (34 cu in.) to *H. habilis*. Most *habilis* specimens had a brain capacity closer to 600 cm³ (37 cu in.) than to 750 cm³ (46 cu in.), which is the maximum size found in *habilis* fossils.

A million years or so after the first tools were made, the situation grew somewhat clearer. By that time all australopithecines were gone and the hominids were *H. ergaster* in Africa and *H. erectus* in Asia (depending on how one classifies the apes, which are often considered hominids). Tools are clearly associated with *H. ergaster* and with *H. erectus*. Furthermore, the tools are much more sophisticated than the simple pebble tools. The main tool for *H. ergaster* was a sort of generalized stone oblong or teardrop that anthropologists like to call by the neutral name of *biface*, although the traditional name of hand axe is commonly employed by the rest of the world. In Asia, *H. erectus* either failed to develop hand axes or used them much more sparingly.

Beyond better stone tools, *H. ergaster* and *H. erectus* were the first creatures on Earth to control fire. No other organism has accomplished this, so fire



HAND AXE The hand axe, or biface, seen here in two views, was the basic tool of the ancestors of humans from about 1,500,000 years ago to about 100,000 years ago. Despite its popularity, no one is sure how it was used—some think it was thrown at game.

might be considered a better defining characteristic of humanity than tool making or language, which form something of a continuum from other animals to humans.

All the hominids before *H. erectus* arose in and stayed in Africa — although fossils in Europe from Georgia could possibly be *H. habilis*. *H. erectus* also first appeared in Africa but soon ventured out to adjoining Europe and Asia. Any land that could be reached by walking or crossing streams was soon populated with the wandering hominids.

In the north of Africa and Europe, about 600,000 years ago, populations of a new species emerged. Some anthropologists term the African and Spanish populations *H. antecessor*. Others group all European fossils into a species designated *H. heidelbergensis*. In either case, by about 200,000 years ago this population had evolved into or been replaced by the Neandertals, now accepted as *H. neanderthalensis*. The Neandertal tool industry brought new techniques and more complex tools, but like the toolkit of *H. ergaster*, the Neandertal toolkit was largely created once and then left alone. Changes over long periods of

time consist of quite small improvements, not major innovations.

At a not clearly identified point in the past, people much like us began to appear, probably in Africa, the original home of all the previous hominids. These people advanced on all the technological fronts pioneered by earlier hominids. But they also introduced something new, which we eventually came to think of as an esthetic sensibility, shared only with the Neandertals.

ARCHAEOLOGY As with anthropology, the science of archaeology did not arise until later, but many of the developments studied by archaeologists occurred during this period. It seems helpful to include in the chronicle under the archaeology heading information concerning the beginnings and ends of the principal civilizations of the period — for example, the settlement of Crete, which marks the beginning of the Minoan civilization. The principal developments of this period include the city-states and kingdoms of Mesopotamia (now Iraq and eastern Turkey), the unification of Egypt, and the development of civilizations in India, China, and Mexico

ASTRONOMY Ancient hominids certainly looked at the sky, but it is difficult to tell at what point in prehistory they recognized the changes that take place each night or over longer periods of time. There is some evidence that people in the Old Stone Age recorded the phases of the Moon. This seems likely as the phases are easily seen, and the period of change involved from beginning to end is less than a month.

After the Agricultural Revolution, people began to create calendars. Farmers need information about the proper time to plant crops. The Sun or stars could be used to determine the year, and in Egypt the annual flood of the Nile. Later Egyptians are known to have used the star Sirius as the calendar star.

The large stone structures from the Neolithic tend to be aligned with the Sun or with a north-south line, suggesting that they were used as observatories. Stonehenge, for example, was almost certainly connected to the solstices, while the Great Pyramid — perfectly sited on a north-south axis — has openings that indicate stars important to Egyptian astronomers.

COMMUNICATION The question of how much and what kind of speech or similar communication (such as gestural) existed before written records is extremely difficult to answer. Looking at the prehistoric archaeological record, however, one can discern a variety of modes of communication that have been preserved. For example, there is evidence that the Neandertals made some ornaments and that they painted something — probably their own bodies, the most common form of artistic expression around the world. *H. sapiens* introduced a wide range of decorative jewelry, played music, and created paintings and sculpture. Although there are a few geometric carvings that may have been produced by Neandertals, recognizable images all date from the time after *H. sapiens* replaced all other members of our genus.

Some enigmatic markings may represent communication but they could also be accidents or the result of doodling. These are bone and antler fragments that contain scratches or notches that some paleoanthropologists have identified as tally marks or even as early calendars. Similar but more clearly intentional scratches on bone have been identified as a map. All of these scratched or notched bone and antler fragments come from the same cultures that made recognizable portraits of many animals and a few humans.

Although it is easy to dispute any single instance of tallies or calendar marks, when all the instances are put together,

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it appears that early humans were beginning to keep records.

No one knows for certain what very early art meant, but there are excellent reasons to suspect that it meant something. A prevalence of images that suggest vulvas or women with sexual features exaggerated and some early phalluses provide a theme running through much art from about 30,000 BP. A different theme emerges about 10,000 years later with many paintings of prey animals, some shown with mysterious "darts" painted at various locations on the body. Many theories have been posed and disposed of with regard to the meaning of the cave paintings. Popular accounts connect them with religion of some sort or perhaps with education. From their inaccessible locations, it is apparent that the cave paintings were not mere decoration.

There was increased need to keep records in New Stone Age (Neolithic) times, for trade over long distances became common. About 8000 BCE, people in the Near East began to use a system of fired clay tokens to record numbers of sheep or measures of grain. For example, one token of a particular shape would be equal to a measure of grain. The token system persisted in one form or another for at least 5000 years. It progressed through a sequence of steps that culminated in the invention of numeration and writing.

Other advances from this period include the gradual improvement of maps. Although some engravings have been interpreted as earlier maps, the first definitely identifiable maps start with Sumerian maps that follow hard on the heels of the invention of writing.

CONSTRUCTION Whether *H. habilis* or *H. rudolfensis* had semipermanent "homes" is far from clear. Certainly there are places where leftover tools and chips from tool making are much more common than others. Perhaps, however, these are the sites of major kills, either

by *habilis* or by predators (in which case *habilis* used the tools to scavenge the site). Or maybe these were favorite places for water. But they might be what anthropologists call living floors, in which case they might have held some sort of permanent dwelling — the beginning of architecture.

It is not until over a million years later that we today can be sure that people were building recognizable huts, although ambiguous evidence for post-holes earlier suggests that the practice may have started with *H. erectus*. The best evidence for houses built by *erectus* comes from the site Terra Amata, dated at 400,000 BP, near what is now Nice, France. There the postholes form ovals 15 m (50 ft) long and 6 m (20 ft) wide. Furthermore, for once there is also rock-hard evidence of housing, since rocks that surround the postholes seem to have been used for bracing or perhaps for holding down the edges of hides. These postholes are often called the remains of the earliest known houses. But some paleoanthropologists remain unconvinced. They want better evidence.

The biodegradability of wood is a major problem for paleoarchaeologists studying housing. Undisputed identification first comes for dwellings made from bone and brick, although no doubt preceded by houses of straw and sticks.

Bricks began to emerge in the Near East about 10,000 BCE in regions where both wood and stone were in short supply. The first bricks were a kind of sun-dried adobe held together without mortar. Mortar and plaster were discovered by at least 8500 BCE. They greatly improved construction with sun-baked bricks.

By the end of the Stone Age, houses were fairly complex, with some even built of stone. For most of the period, however, stone was not used in construction. Temples, tombs, towers, and

mighty works of all sorts were yet to come. Stone construction will be the main agent for these wonders. Indeed, some of the main works from 2000 BCE consist solely of giant stones. Building techniques improved, and large temples and palaces were constructed of stone or brick. Such structures as the pyramids in Egypt required a technology capable of quarrying, moving, and lifting very heavy stones.

Along with tombs, monuments, and buildings, architects and civil engineers of the earliest civilizations built many practical structures. The first stone bridges, large tunnels, dams, aqueducts, and canals were built during this period. Often the beginning of civilization is directly attributed to control of water, especially for irrigated farming.

ENERGY There is much evidence for fire at early hominid sites, although it is possible that the earliest deposits of charcoal are caused by natural fires started by lightning. It seems probable that early hominids used fire for a long period before they learned how to start a fire themselves. Early fire is associated with *H. erectus* or *H. ergaster* sites, where it was most likely used for cooking and as a protection from predators. By 40,000 BCE *H. sapiens* and perhaps *H. neanderthalensis* were using lamps for lighting and perhaps using fire for making ceramics from clay. Although early fires were all based on wood, hunters in plains where wood was scarce learned to fuel fires with bone.

By about 5000 BCE some societies learned to use fire to turn rocks and soil into metal, smelting copper and later tin and lead. A thousand years later, people used fire to make glass from sand and soda. Fire has many other uses, including inducing cracks in stone to aid in quarrying and hardening both stone and wood points or edges.

FOOD & AGRICULTURE Many paleoanthropologists think that our ancestors

and early relatives were gatherers, but only incidental hunters. The best comparison we can make is to the chimpanzees. Both species of chimpanzee live primarily on foraged food, especially fruit, nuts, leaves, and insects. Nevertheless, they like a little red meat on a Saturday night, and they hunt it when the occasion arises. This seems to happen every ten days or so. In general, the males do the hunting, and they share the kill with other males and with females. The australopithecines may have lived much like the chimpanzees, although there is some evidence from tooth size and wear that *Paranthropus robustus* mainly dug and ate roots. Recent studies of the chemistry of fossils suggest that australopithecines did include meat as a part of their diet, even big-toothed *robustus*.

Many animals forage, but few gather (which consists of bringing food back to a central location before eating it). The gathering way of life, even with a little hunting thrown in, does not require much technology. Gathering roots is much easier if done with a digging stick, or *dibble*, a method still used by modern-day hunter-gatherers, and probably employed by very early hominids as well. But digging sticks are very hard to recover from the fossil record. Gatherers also develop materials to use in food transport — perhaps a large leaf or similar natural object (for example, ostrich eggs) in early societies, but woven materials or pots for liquids later.

There is a fair amount of evidence that the next major revolution in sustenance after gathering was not hunting with weapons, but scavenging with stone tools. Cuts and scratches on fossilized bones of antelopes and other food species can be separated under the microscope into those caused by tooth or claw and those caused by pebble tools. Some claim that a preponderance of such bones have most of the tool

scratches on top of the teeth marks, evidence that the lion or tiger or bear got to the food before the hominid did. This might suggest that while *H. habilis* or *H. rudolfensis*, the putative first hunters, could have picked off some small game, such as monkeys, interactions with larger game were limited to scavenging kills made by lions or other predators. In that case, the first tools were primitive butcher knives, not early weapons.

Although there is a good case to be made for *H. habilis* as scavenger, the evidence strongly backs up the claim of *H. ergaster* or *H. erectus* as powerful hunters. Individual sites where *H. ergaster* or *H. erectus* are thought to have hunted may be disputed, however. One authority says that a site containing 800,000-year-old baboon remains mixed with many bifaces (hand axes) at Olorgesailie in southwestern Kenya resulted from a successful planned hunting expedition that involved a nighttime ambush of nearly a hundred baboons that were sleeping in trees. The baboons were knocked from the trees by thrown bifaces and butchered with stone cleavers. A different authority says that the baboon bones and bifaces present at the site were swept there from many individual locations and concentrated by the action of a river. Despite such differences, the overall trend is inescapable. Caves with *erectus* remains also contain bones of butchered animals, some quite large. Evidence supports trapping the ancestors of cattle in a bog in Africa, driving elephants over a cliff in Spain, and similar major kills elsewhere. Certainly, any creature that can control fire can also use it as a tool in hunting.

By the time of the Neandertals and modern humans, hominids were not just hunters, they were extremely successful hunters, the greatest the planet had known. The evidence of this is largely in the huge piles of butchered bones of antelopes, horses, and mam-

moths piled up by hunters of the ice ages. *H. sapiens* probably hunted the larger species to extinction. Certainly, hunting pressure was so great that we eliminated the larger examples of each species, reducing the overall size of horses, antelopes, and beavers by ruthlessly hunting and killing the biggest prey we could find.

Today nutritionists often remind us that people were hunter-gatherers for a million years and were farmers for less than 10,000 years; we have been sedentary factory and office workers for only a couple of hundred years. Since evolution does not proceed very fast, we still have the physical needs of a hunter-gatherer, but we eat like farmers and live like kings. As a result we get fat, develop type II diabetes and high blood pressure, have rotten teeth, and generally are physical wrecks compared with our glorious ancestors. This may be partially true when we compare ourselves with early hunter-gatherers, whose very bones often seem to radiate good health, but it is also clear that today's factory and office workers are generally in better health than farmers were most of the time since the Agricultural Revolution.

Domestication leaves a trace in the archaeological record because domesticated animals and plants have different characteristics from their wild ancestors. Domesticated animals are bred to be less dangerous than wild ones; many domestics are smaller, for example, than their wild counterparts. Pigs have their tusks bred away. Frequently, the breeders aim for neonatality, the evolution of the appearance and behavior of a newborn that persists into adulthood. In other words, dogs are bred to be more like puppies, cats to be more like kittens. Often neonatality results in a foreshortening of the face that is observable in the archaeological record. If preserved, the presence of traits such as increased wooliness in sheep is also a good sign of

domestication. In addition, archaeologists look at sex ratios and butchered body parts found in the record. Breeders eat most of the males and keep the females for further breeding or for milk. They consume all of a pig butchered in the village or at home, while they only bring home the best bacon from one killed far off in the forest.

Similar rules hold for plants. In wild grasses, most of the seeds fall to the ground as soon they are ripe (they "shatter"), but domesticated grasses, such as domesticated wheat, are bred from those that shatter less. Many wild plants, including wild wheats and the progenitor of maize, have their seeds covered with thick and hard-to-remove husks; the domesticated varieties have much thinner coverings. Often the number of edible parts increases, as, for example, the improvement from wild two-row barley to tame six-row barley.

From this kind of evidence and also from drawings and engravings showing people tending animals or plants, archaeologists can trace the step-by-step process of domestication, one that is not complete today, as we continue to find new uses for plants or even use genetic engineering to produce new forms of domesticated plants and animals.

Sometime after the domestication of plants, the digging stick was converted into a simple plow by pulling it along the ground. Probably, people did the pulling at first. There is better evidence for implements used to process food, such as grindstones, than there is for equipment involved in planting or cultivation, most of which was done by hand for the first several thousand years of agriculture. Stone sickles are known early, however; indeed, they predate domestication, being first used for wild grasses, as were the first grindstones.

The first basic tool, the plow, grew from a pulled digging stick at the start of this period. The main early need for a plow was to soften the ground for



ANCESTOR OF MAIZE Teosinte, ear shown at the left, was domesticated as a simple popcorn and eventually became the familiar ear of maize (corn) at the right. The ear in the middle is a hybrid of modern corn and teosinte.

planting. Gradually, farmers learned that it also helped to fertilize the soil and to remove weeds by pulling them or even by turning the weeds into "green manure" (digging weeds into the soil and letting them rot there).

MATERIALS Most biological materials are biodegradable, and for that reason form only a tiny part of the early archaeological record. Nevertheless, no one seriously doubts that such materials were used as the basis of the first technology. Biological materials have continued to be an important part of technology up to the present. Although my computer is almost entirely synthetic, it rests on a wooden table in a wood-framed house, for example. It would be possible today to replace all the wood in my office and house with other materials, but they would be more expensive, less attractive, and in many cases not as good as the wood.

Whether or not archaeologists can find its traces, wood has remained the most used material for most of human history. Worldwide, it probably still is. Wood is strong for its weight, flexible or stiff as required, and still cheap at this point in time.

One advantage of wood is that it is already here. While it is generally necessary to separate wood from the plant, and while for some purposes dead wood is preferable to recently living wood, it is not required in general to process wood. The only need is to shape it. After learning control of fire, it became apparent that for some purposes, such as fashioning spear points, slightly heated and charred wood is superior to untreated wood.

Stone shares with wood the quality of being already present in usable form. Stone exists in more varieties than wood, however. A technologically sophisticated worker knows that cedar is long lasting and splits well, oak is hard, and yew is flexible. It is often possible to substitute one for another and still get a workable tool, although not one as good or as easy to manufacture as if the correct wood were used. With stone the differences are vaster. Flint, shale, obsidian, granite, and chalk are so different that many tools can be made only with an appropriate stone.

Our earliest ancestors probably accomplished tasks with the help of wood or stone objects even before they learned to make wood and stone into tools. Again, about the only window into such early behavior is that into tool use among chimpanzees. Although baboons are stronger and more dangerous than chimpanzees, chimps tend to dominate baboons where the two species frequent the same territory. Jane Goodall thinks that this is because chimpanzees can and do throw branches and stones at baboons when the two species quarrel. Baboons do not know how to throw things, and so they come

to believe that chimps are more powerful than they really are. It seems likely that our weak ancestors and early cousins also threw whatever came to hand as protection against stronger beasts.

When it comes to throwing an object as a weapon, stone is clearly superior to wood for most purposes. Some paleoarchaeologists think that such early tools as bifaces were essentially developed to be thrown at prey. Being hit by a well-thrown object over a kilogram (2 pounds) in weight with sharpened edges would inflict a fairly serious wound. Stone's greater density (weight per unit of volume) not only improves thrown weapons in various ways but also helps in pounding living or inanimate objects — you would not want a hammer with its business end made from wood. A sharpened flint edge is also immensely superior to a broken branch for cutting meat.

The Neolithic was coincident with a technology that did not rely as much on stone tools as the name Neolithic ("new stone") would suggest. There was an increasing tendency to rely on materials other than stone in tool manufacture. For one thing, the increase in human population meant that suitable stone became not as easy to find, perhaps leading to the reduction in the size of stone tools. Also, inventive humans were finding that other materials were better than stone for specific purposes. Archaeologists may also overlook biodegradable materials, such as bone and horn, from early in the Old Stone Age, simply because organic materials do not last as well as stone does.

Although people in Europe learned to fire clay to make it harder (and to mix it with ground-up bone to make it harder yet), the Near East was slow to learn that fire makes clay into a ceramic, such as a brick. But in Europe, where they knew how to make ceramics, they did not need the material for construc-

tion, having plenty of wood and stone, so the Europeans used ceramics first for ornaments and small statues. An innovation of the Mesolithic was regular and widespread use of the ceramic material called pottery. Although European ceramics are known from earlier times, the first pottery comes from Japan. Pottery became common in the Near East toward the end of the Mesolithic as well. Weaving is also known from the later Mesolithic. Other major advances in technology after the Agricultural Revolution included smelting, the production of metals from ores. In Egypt, papyrus — and later, parchment — was being used for writing.

MATHEMATICS Written numbers, in the form of tallies at first, preceded any known form of written words. A major development of the period after the Agricultural Revolution was the invention of ways more complex than tallies to record numbers, leading eventually to numeration systems. In Mesopotamia the early ways of recording numbers seem to have led directly to writing. It is not clear how writing arose in other parts of the world, but numerals probably preceded words in eastern Asia and in the Americas as well. By 4000 years ago, positional notation was in use in Mesopotamia, with separate developments by the Chinese and the Maya some hundreds or thousands of years later. In Mesopotamia, the base-60 system of numeration led to a mathematics capable of solving quadratic equations.

Geometric designs are even older than the first recorded numbers, but it is a big step from carving a triangle to measuring it and computing its area. Systems of measurement, like numeration systems, appear to have arisen from trade needs. Later, something closer to true geometry also progressed in both Egypt and Mesopotamia, with improvements in the ability to measure

area and volume, better values for π , and the discovery of the Pythagorean theorem. Toward the end of the period, symbols for zero as a placeholder were introduced.

Measurement with standard measures, which developed during this period, is treated in the chronicle as applied mathematics, unless new measurement tools are involved.

MEDICINE & HEALTH Recorded medical science had its beginning during this period (although there was undoubtedly Stone Age medicine that has largely been lost from the archaeological record). The Egyptian cult of the dead, ironically, made the greatest early contributions, since the embalmers and morticians from as early as the third millennium needed to understand human anatomy (with plenty of opportunity to observe any visible causes of death) and worked with a number of organic chemicals that they used to preserve organs and whole bodies. Thus, early Egyptian medicine involved surgery as well as internal medications, while early Mesopotamian medicine revolved around external application of medication. Still, the Code of Hammurabi stated that a fair price for successful surgery should be between two and ten shekels, but an unsuccessful surgeon should have his hands cut off. An Egyptian surgical manual of about the same time provides sensible procedures for many types of operations. Egyptian medicine, the most advanced of its time, also included various drugs, some of which are recognized as effective today.

TOOLS The most familiar stone tools are those triangular devices that archaeologists call *points*. The first points may have been spearheads, but also may have been used in other ways, perhaps as scrapers or knives. Eventually — the exact time is uncertain — the bow and arrow was invented. After that, both

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stone and bone points were specifically adapted as arrowheads. The term *point* continues to be used as it is fairly neutral as to how the point was employed, although barbed harpoon points are generally referred to as harpoons, not points. Smaller points could have been used for the sharp edge of a sickle or for the teeth of a saw.

Spears, harpoons, and arrows are not the only tools used for striking at a distance. The boomerang is known from artifacts that date from well before the first spear thrower, harpoon, and bow. Very likely the sling preceded the boomerang, and may date from 100,000 years before the bow and arrow. It is difficult to tell, however, because the sling itself is biodegradable and the missiles used might be any smooth stones.

It can be argued that the seminal tool of civilization was the potter's wheel —

from which various other devices that use rotary motion flow. The potter's wheel not only made better pots more easily, but (in Greek hands) became a tool for painting, smoothing, and grooving them. The last two operations on pots do the same for clay as a lathe does for wood, and it is easy to see how the concept of the lathe can flow from the potter's wheel.

Trade and business propelled some of the other devices of the age. It is difficult to trade in materials unless you can measure them, and for many materials their mass is the main measure. The invention of the balance scale by the Egyptians enabled merchants to measure mass.

Business is difficult to arrange without the parties operating on the same time schedule, prompting this period to

usher in the introduction of various forms of the water clock and sundial.

TRANSPORTATION Where there was snow, sledges (sleds) were used for transporting goods, although the sledges probably were pulled by humans. During the early Neolithic period there is no evidence of the use of animals in transportation; however, this could have started as soon as cattle were domesticated. The evidence for sledges is scanty, although they certainly were used before the first wheeled vehicle. The later part of this period, starting around 3500 BCE, saw the first wheeled vehicles, the first sailing ships, canals used for transportation, tunnels, and various ways to use the horse and mule in transportation. The basic methods of transportation that were introduced during this period persisted with slight improvements until the 18th century.

CHRONICLE

2,600,000 BCE

I Tools

Hominids in Africa manufacture simple stone implements known as pebble tools, the first known evidence of technology. The stone tool assembly, or toolkit, is called Oldowan after the Olduvai Gorge in Tanzania, although the oldest known sites are from the Omo Valley in Ethiopia. *Homo habilis* ("handy man"), a small, bipedal, large-brained (for the time) creature, is so named because it is thought that the first stone tools were produced by this hominid. See also 2,500,000 BCE TOOL.

2,500,000 BCE

I Tools

A hominid, an australopithe-

cine classed as *Australopithecus garhi*, lives at Bouri on the Middle Awash River in Ethiopia, as is known from a single fossil skull. The skull was found along with other unidentified hominid fossils, butchered animals, and primitive stone tools, raising the possibility that australopithecines used tools found at various early sites. See also 2,600,000 BCE TOOL; 1,900,000 BCE TOOL.

2,000,000 BCE

► Anthropology

The first actual fossils of *Homo habilis*, along with those that some anthropologists identify as *H. rudolfensis*, date from this time, although it is assumed that both species arose earlier. Evidence suggests that this type of small hominid persisted until about

1,500,000 years ago. See also 1,900,000 BCE ANTH.

1,900,000 BCE

► Anthropology

A new species of *Homo* arises in Africa. Some anthropologists call this species *Homo ergaster* ("work man"), while others feel that it is the earliest manifestation of *Homo erectus* ("erect man"). See also 2,000,000 BCE ANTH; 1,000,000 BCE ANTH.

► Construction

Some archaeological sites in the Olduvai Gorge in Tanzania from around this time until about 1,600,000 BP are thought by some to be living floors — that is, home bases or campsites; at these sites, tools and hominid remains seem to be concentrated; other paleoanthropologists

believe that such concentrations are caused by agencies such as river currents washing tools from various sites to a single location, and not from use as home bases. See also 400,000 BCE CONS.

► Energy

Changes in physiology of fossils from this time suggest that humans' ancestors in East Africa have discovered how to use fire to cook tubers, an improved food source over soft fruits, according to Richard Wrangham of Harvard. See also 24,000 BCE FOOD.

I Tools

The oldest known stone tool industry is characterized by remains that start about this time at the Olduvai Gorge in northern Tanzania, accounting for the name Oldowan; the choppers and scrapers are simple chips of stone and are

The best rocks for tools

Most people know that stone “arrowheads” were made from a kind of rock called *flint*, but otherwise have no idea about the relationship of stone as a material to tool manufacture and use. Early hominids were more discerning; they had to be to survive.

Flint The best material for making a great variety of stone tools, flint is closely related to the semiprecious stones called carnelian, chrysoprase, and jasper—uniform, red, green, or yellow forms of the mineral chalcedony. Large deposits of gray or black chalcedony are called chert; small pieces, called nodules, of gray or black chalcedony found in limestone or chalk are called flint. The harder and more chemically stable flint can easily be picked from its limestone or chalk background.

No one knows what causes flint nodules to appear where they do. Chalcedony is a form of quartz that has tiny crystals and is very dense; hence, it is silicon dioxide, also known to mineralogists as silica, just as quartz is. Limestone and chalk are both calcium carbonate, a different mineral entirely. Veins of silicon dioxide often form as a result of solutions of water containing the silica, especially solutions in superheated water. The solutions travel through limestone or chalk and leave the silica behind when they cool.

Because of its crystal structure, flint breaks in a pattern geologists call a conchoidal fracture; this produces sharp edges but does not propagate throughout a stone, splitting or shattering it. Furthermore, there are no preferential fracture planes, so small pieces of almost any shape can be removed. A nodule broken in two could be the first manufactured stone tool, indistinguishable as a tool today except for microscopic wear patterns that indicate use. The beautifully scalloped surfaces of many later stone tools are one result of the conchoidal fracture pattern.

In the absence of the fine-grained flints, our ancestors often used the best approximations they could find — quartz (silicon dioxide with a larger crystal structure) and rocks or other materials infused with silica, including petrified wood.

Obsidian Anyone who has picked up the remains of a shattered glass dish or bottle knows that glass also breaks in a pattern that causes very sharp edges. The break is also a conchoidal fracture, but because glass is more brittle than flint, the glass not only fractures but also easily shatters. A fragment of broken glass can have a very sharp cutting edge that can be used as a tool. The utility of broken glass was not lost on our ancestors. Although manufacture of glass from silicon dioxide (sand that is formed from small particles of quartz) did not start as far as we know until about 1400 BCE, implements made from natural glass called obsidian are among the earliest stone tools. Obsidian is a rock produced when granite or rhyolite, quartz combined with feldspar and mica, is melted by a volcano and then cooled very quickly. Some dark forms of obsidian are known as pitchstone. Opal, a glassy form of quartz, was also used for stone tools, but it is less common than obsidian. As with substitutes for flint, volcanic rocks such as lavas or those formed from hot ash flows were sometimes used instead of volcanic glasses.

Other rocks A third type of stone tool material includes various rocks, such as quartzites or hardened shales, that had been hardened (metamorphosed) by great heat and pressure in the interior of Earth. Quartzites that are metamorphosed sandstones became particularly useful for axe and adz heads after the practice of grinding edges was introduced as part of the Neolithic Revolution. Quartzite axe heads have the advantage of a structure in which cracks do not propagate far, so the tools maintain their integrity even when their edge is chipped. Very early stone bifaces (hand axes) were also made from quartzite, which can be easily flaked to produce a useful but not very attractive tool. As our ancestors became more experienced, they first shifted to the volcanic lavas that could yield smaller, better looking flakes with sharper edges. Eventually, flint came to predominate, even in regions where flint is not a common rock.

Flint and obsidian were mined and traded in the later Stone Age. As population increased and there was less flint to go around, new techniques, such as manufacture of microliths, were developed. Microliths involve flint or obsidian cutting edges embedded in wood, with the bulk of the tool embodying the wooden portion.



PEBBLE TOOLS The earliest known stone tools were simple pebbles with one edge created by breaking the pebble.

sometimes called pebble tools; some Oldowan-type industries date from an earlier time, especially in Ethiopia, the Democratic Republic of Congo, and Malawi. See also 1,500,000 BCE TOOL.

1,700,000

➤ Energy

Stone tools are heated to high temperatures in East Africa,

suggesting that hominids, probably *Homo ergaster*, know how to control fire. See also 1,900,000 BCE ENER; 1,600,000 BCE ENER.

1,600,000

➤ Energy

Patches of baked earth near *Homo ergaster* or *erectus* sites at Koobi Fora and Chesowanja (Kenya) suggest that

hominids are regularly using fire at hearth sites. See also 1,700,000 BCE ENER; 1,000,000 BCE ENER.

➤ Transportation

Homo erectus probably migrates to Asia and to Georgia in Europe about this time, the first hominid to leave Africa. See also 50,000 BCE TRAN.

1,500,000 BCE

1,500,000 BCE

I Tools

Acheulean artifact assemblies, which will continue to be produced until 200,000 BCE, are first left behind in Africa, probably by *Homo ergaster* or *erectus*. This toolkit is characterized by bifaces (hand axes, cleavers, and picks). Acheulean bifaces are typically large, ovoid stones from which flakes have been removed by hammerstones. Their exact purpose is unknown, although it is generally believed that they are basically all-purpose tools. *See also* 1,900,000 BCE TOOL; 400,000 BCE TOOL.

1,000,000 BCE

◀ Anthropology

A few fossils from Africa (and perhaps some from Asia) can be interpreted as some form of archaic *Homo sapiens*, although fully modern humans are far in the future. *See also* 1,900,000 BCE ANTH; 200,000 BCE ANTH.

↗ Energy

Ancient hearths found in the Swartkrans cave (South Africa) indicate that *Homo ergaster* or *erectus* uses fire. *See also* 1,600,000 BCE ENER; 600,000 BCE ENER.

800,000 BCE

I Tools

Stone tools found in the Bose Basin of southern China are apparently made by *Homo erectus* in response to a meteorite fall that destroyed vegetation and exposed deposits of quartz, quartzite, and sandstone. These are the earliest stone tools

found in eastern Asia. *See also* 1,600,000 BCE TRAN.

600,000 BCE

↗ Energy

A thick ash layer formed between this time and 400,000 BCE in L'Escale Cave (southeastern France) has sometimes been viewed as the earliest known evidence of fire made by hominids in Europe, although it cannot be definitely established that it is not the result of naturally caused fires. *See also* 1,000,000 BCE ENER; 40,000 BCE ENER.

400,000 BCE

■ Construction

Evidence at Terra Amata (near Nice, France) indicates that early humans living there occupied oval huts that are 15 m (50 ft) by 6 m (20 ft). This is the first evidence of housing construction. *See also* 1,900,000 BCE CONS; 28,000 BCE CONS.

◊ Materials

The earliest known wooden artifacts are three spears from 0.78 m (2 ft 9 in.) to 2.30 m (7 ft 6 in.) long, found in a coal mine along with stone tools and broken animal bones at Schoningen (Germany). Two appear to be intended for throwing at prey and one for thrusting. *See also* 120,000 BCE MATR.

I Tools

The burin, thought to be the primary tool for engraving and carving such materials as bone, antler, ivory, and wood, becomes common, as do end-scrapers (*grattoirs*), thought to have been used for hide scraping or woodworking. *See also*

1,500,000 BCE TOOL; 200,000 BCE TOOL.

350,000 BCE

I Tools

Hand axes found by Sir John Frere [b. Norfolk, England, August 10, 1740, d. East Dereham, Norfolk, England, July 12, 1807] in a brickyard at Hoxne, Suffolk, England are made about this time. *See also* 1790 CE ARCH.

240,000 BCE

I Tools

Blades and blade cores thought to date from this time occur at Kapthurin (Kenya). *See also* 40,000 BCE TOOL.

200,000 BCE

◀ Anthropology

The earliest Neandertals are known from this time. These puzzling hominids are clearly in the genus *Homo*, but authorities differ on whether they can be classed as a subspecies of *Homo sapiens* or whether they are a different species that arose separately from *H. erectus* or possibly from archaic *H. sapiens*. They have a technology all their own as well, one that is more diverse and advanced than that of *H. erectus*, but much more stable than that of fully modern *H. sapiens*. *See also* 1,000,000 BCE ANTH; 90,000 BCE ANTH.

I Tools

Although more characteristic of Middle Paleolithic industries, the first Levallois prepared-core flake tools begin to appear at this time. In the Levallois technology, the core is carefully shaped into a regular

block of stone from which very large, thin, nearly uniform flakes that can be used without further shaping are struck. Neandertal technology changes little over periods as long as 100,000 years. *See also* 400,000 BCE TOOL; 150,000 BCE TOOL.

Well-made side scrapers begin to become common, suggesting that *Homo erectus* is now manufacturing clothing from hides. *See also* 19,000 BCE MATR.

150,000 BCE

I Tools

The earliest known Mousterian tool industries start at such sites as Biache in northwestern France. This tool making tradition, associated almost completely with Neandertals, is characterized by Levallois and discoidal-core manufacturing of side scrapers, backed knives, hand axes, and points. *See also* 200,000 BCE TOOL; 40,000 BCE TOOL.

130,000 BCE

◀ Anthropology

The Apollo-11 site in the Orange River Valley (Namibia), excavated by Wolfgang Erich Wendt from 1969 to 1972, is first occupied. It remains occupied until 4000 BCE. *See also* 200,000 BCE ANTH; 44,000 BCE COMM.

◊ Materials

In Africa ground stone is used in the manufacture of bowls, mortars, and pestles. *See also* 40,000 BCE MATR.

120,000 BCE

◊ Materials

The earliest known example of

Stone technologies of the Old Stone Age

Many different stone technologies (often called tool assemblies, industries, or toolkits) have been named by anthropologists. The first, the Oldowan industry, produced pebble tools by simply breaking off bits of rock, called *flakes*, with virtually no retouching of the material left behind. The larger piece of rock from which the flakes were broken is known as the *core*. The core is the main Oldowan tool, although some flakes might also have been used as tools.

The second industry, called Acheulean, is a toolkit based on bifaces (hand axes or cleavers). Although the tools are still primarily the cores, produced by hammering with another stone or, in later versions, by hammering with something softer than stone, such as wood or bone, the cores and some of the larger flakes are retouched into tools that anyone can recognize as artificial. In Europe, the same tool assembly is often called Abbevillian for the early "hard-hammer" phase and Chellan for the later "soft-hammer" stage. This tool industry was virtually coextensive with the rise and domination of *Homo erectus*. It also persisted for at least a million years. In some places, the Acheulean remained the basic industry for half a million years more. When it was replaced, the new industry was coincident with Neandertals or early *Homo sapiens*.

The next major development, associated in Europe with the Neandertals, is the Mousterian assembly. The Mousterian toolkit

is based on side scrapers and projectile points. The later version of the industry uses a new technique, called prepared core or Levallois, in which the core is preshaped to produce a particular type of flake. The flake is the primary tool, not the core.

The next stage is divided into several parts in the European nomenclature, with the early part called the Perigordian industry and the next, and more famous, labeled the Aurignacian. The main difference is that the tools of the Aurignacian are noticeably better made than those of the Perigordian. These industries used blade knives and the pointed stone tools called *burins*, similar to modern metal burins used in engraving metal and stone. Tools of other materials are also known from these and later times.

Three later tool assemblies complete the Old Stone Age. The Gravettian used smaller blades than the Aurignacian, often with one edge, called the back, blunted, as if to protect the user's fingers. Together, the Perigordian, Aurignacian, and Gravettian industries in Europe lasted from about 32,000 BP to about 18,000 BP. After 18,000 BP there were two other well-known European tool industries. The Solutrean is primarily known for its laurel-leaf blades, so symmetrical and thin that they are sometimes thought to have been too beautiful to have a practical purpose. The last of the Old Stone Age industries made no innovations in stone working; this transition to the New Stone Age is primarily differentiated by the use of many tools of other materials. This industry is labeled the Magdalenian.

a charred wood spear is associated with an elephant carcass found at a site called Lehringen (Germany). See also 400,000 BCE MATR; 5300 BCE MATR.

90,000 BCE

► Anthropology

By this time there is a significant amount of evidence in the fossil record that an archaic form of *Homo sapiens* is present in Africa. There is also limited evidence that fully modern *Homo sapiens* is present this early. See also 200,000 BCE ANTH.

I Tools

Barbed bone harpoons and points at the Katanda site on the Semliki River (Democratic Republic of Congo) are thought to date from this time. See also 16,000 BCE TOOL.

80,000 BCE

↳ Communication

Neandertal humans bury their dead in graves with symbolic use of red ochre dyes at the Regourdou site in southwestern France. See also 7500 BCE CONS.

77,000 BCE

↳ Communication

Archaic *Homo sapiens* occupy Blombos Cave, which now overlooks the Indian Ocean at the southernmost tip of Africa. They leave behind the earliest known bone tools as well as fishing gear and more than 8000 pieces of ochre (thought to have been used for decorating bodies). Two pieces of ochre appear to have been deliberately

smoothed to a flat surface. These have geometric designs incised on them, the first known human-made designs. See also 45,000 BCE COMM.

50,000 BCE

↗ Transportation

Based on dating of bone fragments from central Australia, early humans may have reached that continent, although other sites all give much later dates. See also 1,600,000 BCE TRAN; 45,000 BCE TRAN.

45,000 BCE

↳ Communication

A carved mammoth tooth and other incised bone objects from the Neandertal Tata site (Hungary) are among the ear-

liest carvings and incised objects known. Ground pigments are also found at the site. The earliest recognizable jewelry of any type consists of ostrich-shell beads from the Border Cave (South Africa). See also 77,000 BCE COMM; 40,000 BCE COMM.

A perforated part of the bone of an antelope or other bovine animal is claimed by some to be the oldest known musical instrument, a form of whistle. Indisputable whistles date from more than 15,000 years later. See also 28,000 BCE COMM.

↗ Transportation

Stone tools are left along the Nepean River (near Sydney, Australia), substantial evidence of an early human presence. See also 50,000 BCE TRAN; 35,000 BCE TRAN.

The first immigrants

The first proof we have that our ancestors crossed a substantial body of water is the presence of stone tools in Japan that date from 100,000 BP. Not much is known about the makers of the tools, but the mainland at that time was probably inhabited by a late population of *Homo erectus*. Japan is about 150 km (90 mi) from Korea, but there are several islands along the route. The earliest settlers in Japan must have traveled by raft or boat. Unlike England, which was linked to the Eurasian continent at the height of the most recent Ice Age, Japan is separated from Asia by deep waters that would have persisted even when sea levels were lower.

Homo sapiens may have crossed a substantial body of water on its way toward the desert of central Australia, where traces of human occupation have been dated at 50,000 years BP. (Dating in 2003 shows humans at Lake Mungo, Australia, between 50,000 and 46,000 years BP.) As with the occupation of Japan, islands along the way helped. Early people are thought to have paddled across the Indian Ocean in short hops from one island to another.

During the periods of low sea level before melting of ice caps about 18,000 years BP, the oceans were about 130 m (425 ft) lower than at present. Thus, early humans could have walked most of the way across what is now Indonesia before encountering deep waters that separated other islands and Australia from Asia.

There is scattered evidence that suggests that a few humans crossed the Pacific some 20,000 to 40,000 years ago, traveling from Asia to South America. Most authorities, however, believe that all regions except for Australia and islands were populated via land. In this view, South America received its first people from North Americans whose ancestors traveled from Asia about 12,000 to 18,000 years ago when lowered sea levels created a land bridge at the same time as shifting ice left the land bridge uncovered for a few centuries.

The main islands of the Mediterranean, including Sicily, Crete, Cyprus, Rhodes, and many others, were all settled in Neolithic times (c. 10,000 BP), if not before. By the Bronze Age several of these islands, notably Crete and the Cyclades, contained some of the most advanced civilizations of the day, surely based mainly on trade and shipping.

44,000 BCE

Communication

Humans or their ancestors at the Apollo-11 site in the Orange River Valley of Namibia paint slabs, the oldest painted “art” found in Africa. Fragments of the slabs were excavated by Wolfgang Erich Wendt from 1969 to 1972. See also 130,000 BCE ANTH; 18,000 BCE COMM.

40,000 BCE

Communication

Humans in Eurasia wear beads, bracelets, pins, rings, pendants, diadems, and pectorals. See also 45,000 BCE COMM.

Energy

Construction of hearths in northern latitudes begins to improve noticeably. Stone borders are arranged for heat retention and to direct air flow. Some hearths are enclosed in clay walls and may be used as kilns for ceramic production,

although they may also be used for baking or other purposes. See also 600,000 BCE ENER; 28,000 BCE MATR.

Simple forms of stone lamps are in use, probably fueled with animal fat and using grass or moss for a wick. See also 3500 BCE ENER.

Materials

Ground stone axes are made on the Huon Peninsula of New Guinea. See also 130,000 BCE MATR; 32,000 BCE TOOL.

Tools

The earliest stone-tool industry in Europe to include blades is known from the Bacho Kiro site (Bulgaria). See also 150,000 BCE TOOL; 38,000 BCE TOOL.

38,000 BCE

Tools

Microlithic technology, which gradually becomes dominant starting about 20,000 years BP, begins now if finds from the Matupi Cave (eastern Democ-

ratic Republic of Congo) are correctly dated. See also 40,000 BCE TOOL; 15,000 BCE TOOL.

35,000 BCE

Transportation

People cross a land bridge from Australia into Tasmania. Changing sea levels eventually make Tasmania an isolated island, with its last land connection to Australia submerged about 10,000 BCE. See also 45,000 BCE TRAN; 28,000 BCE TRAN.

33,000 BCE

Tools

The earliest remains of bone, antler, and ivory objects, especially tubular beads, are found in central and southwestern France and northeastern Spain. The tool assembly is known as the Chatelperronian from a site at the Grotte des Fées at Châtelperron (France). See also 77,000 BCE COMM; 32,000 BCE TOOL.

32,000 BCE

Tools

In Europe a tool-making industry termed the Aurignacian is the characteristic toolkit of the later Old Stone Age. It features blades, points, scrapers, and burins of stone as well as tools worked from bone and antlers. One of the main diagnostic tools for the period is a type of spearhead made from bone with a split base. See also 33,000 BCE TOOL; 26,000 BCE TOOL.

In Australia, people begin to make edge-ground axes, thought to have been used for cutting branches off trees. The oldest known example is from Sandy Creek, Queensland. See also 130,000 BCE MATR; 7500 BCE TOOL.

30,000 BCE

Anthropology

About this time fully modern *Homo sapiens* is the only

Machines that go around

We often picture machines with rotating parts. Rotation at less than the size of astronomical bodies and greater than the size of molecules is difficult to come by in nature. Pulleys are the primary simple machines that use rotation, but they were probably not the first used for rotation. Drilling holes by hand may be the first human use for rotary motion. One of the earliest machines using rotation is a rather complex device, the bow drill. A rod, such as an arrow shaft, is placed in a loop of a bowstring; as the bow is moved back and forth, the linear motion is transformed into rapid rotary motion. Today we are most familiar with the bow drill for starting fires. The presence of many beads with what appear to be drilled holes suggests that the device was known in Neolithic times or even in the Late Stone Age. Drilling is difficult to do without some machine help, so mass-produced beads with drilled holes suggest some sort of drilling machine.

Spinning fibers into string was developed early in the Neolith-

ic, before civilization, but that does not mean that spinning wheels had been invented. The first spinning was entirely by hand and used a simple stick called a spindle as a storage device, but soon people were turning the spindle as part of the spinning process. The spindle's speed of rotation could be improved by adding a heavy disk, called a whorl. This may have been the second application of rotary motion.

The key development in the early history of machines is rotary motion in the form of a wheel. It is almost certain that the first wheels were simple potter's wheels rotated by hand. Potter's wheels were not invented until thousands of years after the first fired pots were made, however. Very soon after the introduction of potter's wheels, there is evidence for wheeled vehicles and simple pulleys.

The next round of more sophisticated machines involved devices for turning rotary motion into back-and-forth motion (the reverse of the way a bow drill works). Treadmills were one of the main ways to provide rotary motion, with people or animals running inside of wheels as pet hamsters and gerbils do today.

member of the genus left in Europe, since the Neandertals are no longer present. There may be a remnant *H. erectus* population on Java until perhaps 28,000 BCE. From this time technological change becomes increasingly swift. *See also* 90,000 BCE ANTH.

Communication

The earliest recovered animal images are made. These are detailed and sophisticated three-dimensional carvings of lions, horses, bison, and mammoths. A carving of a horse in mammoth ivory found near Vogelherd (Germany) is often cited as the earliest known animal carving. *See also* 20,000 BCE COMM.

Paintings of hundreds of animals are made in Chauvet Cave (southeastern France), the first large group of such paintings in Europe (dating based on radiocarbon analysis of charcoal). Over the next 6000 to 7000 years humans visit the cave (based on charcoal samples found on the



FIRST CARVED ANIMAL The figure of a horse from Vogelherd Cave in Germany, dating from 30,000 BCE, is among the earliest known realistic carvings. It appears as a work of art to modern eyes as well.

cave floor), after which there is no known visit until December 18, 1994. *See also* 20,000 BCE COMM.

Mathematics

Paleolithic peoples use tallies on the bones of animals, ivory, and stone to record numbers (central Europe and France). For example, a wolf bone from this period shows 55 cuts arranged in groups of 5. *See also* 28,000 BCE AST.

Tools

Microliths are made (China). *See also* 18,000 BCE TOOL.

28,000 BCE

Astronomy

A sketch carved into bone, discovered at Blanchard (France), appears to be a record of the phases of the Moon. *See also* 30,000 BCE MATH.

Communication

The earliest known unequivocally identified musical instruments, flutes and whistles crafted of bird or bear bones or reindeer antlers, are made. The instruments were found from France deep into central Europe and the Russian Plain. *See also* 45,000 BCE COMM; 25,000 BCE COMM.

Beads, bracelets, and pendants are worn by humans. *See also* 40,000 BCE COMM; 16,000 BCE COMM.

People carve and engrave vulvas and, somewhat more rarely, phalluses (France). *See also* 25,000 BCE COMM.

Construction

People from Gravettian cultures at sites such as Pavlov and Dolni Věstonice (Czech Republic) and Kostenki (Russia) build huts that use mammoth bone for support if wood is not available. *See also* 400,000 BCE CONS; 13,000 BCE CONS.

Materials

The earliest fired ceramics, found at sites in the Pavlov Hills of Moravia (Czech Republic) and made from the local loess, are manufactured starting about this time. The small statues and various-shaped blobs may have been intended to explode when refired so the shards could be used in divination; most are found shattered. Animals represented are nearly all predators, while human statuettes are the famous Venus figurines (which occur later than the very first ceramics). *See also* 40,000 BCE MATR; 24,000 BCE MATR.

28,000 BCE–26,000 BCE

✈ Transportation

People arrive on Buka Island in the northern Solomons, probably by sailing from New Guinea. *See also* 35,000 BCE TRAN.

26,000 BCE

🏗 Construction

Perigordian sites in southwestern France show complex arrangements of hearths, slabs, and postholes, implying complex living or storage structures. *See also* 40,000 BCE ENER.

⚡ Energy

Gravettian cultures in Europe burn bone in deep pit-hearths for heat and probably for cooking. *See also* 40,000 BCE ENER.

I Tools

Single-backed points and burins characterize the Gravettian tool assemblage found throughout much of Europe. *See also* 19,000 BCE TOOL.

25,000 BCE

📞 Communication

Music is produced by humans according to archaeological evidence of cave paintings, footprints in caves that appear to be those of dancers, and carved bones that appear to be wind and percussion instruments. *See also* 28,000 BCE COMM.

Σ Mathematics

People make artifacts with primitive geometrical designs.

See also 77,000 BCE COMM; 9500 BCE MATH.

24,000 BCE

🍴 Food & agriculture

Pits dug at sites in the East European plain constitute the first unequivocal evidence of food storage over winter. The same pits are apparently used during summer for storage of such nonfood items as fuel and raw materials for manufacture of tools and jewelry. *See also* 1,900,000 BCE ENER; 16,000 BCE FOOD.

❖ Materials

The Venus figurines, small statues of faceless pregnant women with large breasts and buttocks, are made in Europe. They will continue to be manufactured for the next 2000 years and are among the old-

The first ceramics

Ceramics are produced by heating natural earth until it changes form (without melting — glasses are formed by earth heated until it melts and then cools). Ceramics are different from merely dried earth or clay, which soften when rewet. Cements and plasters, although similar after hardening in some properties to ceramics, are produced by powdering a mineral and bonding the grains together with water. The high heat at which ceramics are produced drives off water chemically bound to the earth as well as any water that has soaked into it. The result of such heating, depending in part on the type of clay or earth, can be terra cotta, stoneware, china, porcelain, brick, or tile. True ceramics appear rarely in nature, but are sometimes the result of lightning strikes and forest fires. From the control of fire by *Homo erectus* to the accidental production of ceramics is a very short step. Apparently, the deliberate production of ceramics had to wait until the more inventive *Homo sapiens* arrived on the scene.

At one time archaeologists believed that deliberate ceramics were a fairly recent discovery, 10,000 years old at the most. A popular theory was that basketry was invented first, but baskets do not hold liquids well. According to this theory, early people solved this problem by lining baskets with clay, which is impermeable. Sometimes baskets so lined got burned and the clay lining was left

behind as a pot. Eventually, people found that they did not have to start with the basket. This theory is reminiscent of Charles Lamb's famous essay on the discovery of roast pig via burning down the house.

Ceramics may or may not precede basketry (which is, of course, biodegradable and easily lost from the archaeological record), but they certainly date much before 10,000 BCE. Furthermore, ceramics were being deliberately made well before the first known ceramic pot. About 28,000 BCE, in the region now known as the Czech Republic, people built kilns and produced small ceramic figures and beads. Ovens that may have been kilns as well go back another 14,000 years.

Practical ceramics — pottery and brick — start with the Neolithic Revolution. The first bricks, however, were not ceramics; they were adobe, clay or mud hardened by drying but without the chemically bound water driven off by heat. When kiln-dried bricks became available, the cost of making them resulted in their being reserved for special monumental buildings; the common people continued to build houses with sun-dried brick.

Pottery was shaped by hand during the Neolithic. Sometimes a large pot would be built and fired in sections that were then glued together with clay and fired again. The invention of the potter's wheel near the start of civilization was a great step, leading not only to better pottery but also to the general principle of the wheel for use in transportation and machinery.

est ceramic objects known made by humans. Many are marked in ways that appear to indicate caps or other forms of clothing. *See also* 28,000 BCE MATR.

23,000 BCE

Construction

Sites in the Pavlov Hills of Moravia (Czech Republic) show that round, oval, and oblong surface and semisubterranean dwellings are constructed. *See also* 26,000 BCE CONS; 7000 BCE CONS.

20,000 BCE

Communication

The earliest animal engravings in the Altamira Cave (northwestern Spain) are made, although the cave's famous red-and-black paintings are from a later date. *See also* 30,000 BCE COMM; 13,000 BCE COMM.

19,000 BCE

Materials

Bone and antler needles are made, suggesting that clothing sewn together with threads of sinew or plant material may have come into use (France and Spain). *See also* 24,000 BCE MATR; 13,000 BCE MATR.

I Tools

The Solutrean tool making industry (France and Spain) is characterized by large symmetrical stone tools known as laurel-leaf points. The exact purpose of these points is unknown, as they are too thin and well-made to be used for normal tasks. Some archaeologists have suggested that they were made for their aesthetic value, which appears great to modern eyes. A Solutrean technological innovation is treating the flint with heat, giving their laurel-leaf blades a sheen like porcelain and also

making the stone easier to work.

18,000 BCE

Communication

Ostrich-shell beads are manufactured at the Apollo-11 site (Namibia). *See also* 44,400 BCE COMM.

II Food & agriculture

The domesticated cat diverges from the wild cats of Europe according to DNA evidence. *See also* 3000 BCE FOOD.

saws. *See also* 30,000 BCE TOOL; 15,000 BCE TOOL.

17,000 BCE

I Tools

Bone harpoons are left at the Ishango site (Democratic Republic of Congo). These are the earliest well-dated examples of harpoons. *See also* 90,000 BCE TOOL; 15,000 BCE TOOL.

16,000 BCE

Communication

People in the Périgord region (France) make pendants that have what appear to be allegorical scenes carved into them, such as a bison's head surrounded by a schematic representation of six or more people (found at Raymonden-Chancelade). *See also* 28,000 BCE COMM.

Stone technology of the Middle Stone Age and Neolithic

Many anthropologists recognize that the end of the Old Stone Age was a significant transition period and label this era the Middle Stone Age. In any case, there is a dramatic change observable in stone tools. This tradition involves the reduction of points and other tools to such a small size that they are called microliths; this tendency actually began with the previous Magdalenian industry.

The first industry to be based largely on microliths, dated from about 11,500 BP to about 9000 BP, is known from its French manifestation as Azilian. There are clues that suggest that microlithic technology was inspired at least in part by the growing human population and its drain on local resources, including good stone for tools. Similar to Azilian, although somewhat different in detail, microlithic industries that followed in France are called the Sauveterrian (to 7500 BP) and Tardenosian (to 6000 BP). Other parts of Europe as well as other continents had corresponding

industries with different names. By the end of this tradition, there are so many individual names given that only specialists know them.

Coexistent with these industries as well as following them, toolkits involved several different types of ground-stone tools, especially axes and adzes (an adz is essentially an axe with its blade turned 90 degrees, used mainly to shape large pieces of wood). It is thought that Neolithic farmers replaced flaked stone edges with ground ones to have the kind of axes needed in clearing land. The modern re-creators of stone technology have shown that, although flaked tools are just as sharp as ground ones, ground edges hold up much better in hard use, as in chopping down trees. Furthermore, if they lose their edge, ground tools are easily reground.

Throughout the early history of stone tools, there has been a progressive improvement in efficiency. The length of the cutting edge obtained from one kg (2.2 lb) of stone is 60 cm (24 in.) for the early pebble tools, but progresses to 2000 cm (790 in.) in microliths.

New materials: tooth, bone, and horn

Remember the australopithecine in the movie *2001: A Space Odyssey* that beat up on invaders with a bone and then tossed the bone triumphantly into the air, where it turned into a space ship? Although bone was surely recognized as useful from early on, it was not until modern-type human beings arrived on the scene that its full potential as a material was utilized.

Before bone, however, ivory (that is, the material of animal teeth) was sometimes used, especially for ornaments. Ivory is both denser and less fibrous than bone, making it easier to work. But it is not as available as bone. Mammoth ivory, although not as plentiful as mammoth bone in northern regions, was fairly common.

Somewhat farther south, reindeer horn was a popular material. Although we perceive horn as a single substance, horns of deer, antelope, cattle, giraffe, and rhinoceros are not much alike. Deer and giraffe horn are different forms of modified bone. True horn is derived from the skin and is something like many fine hairs that have grown together. Antelope and cattle horn consist of a core of bone covered with true horn. Rhinoceros horn is all true horn. Since reindeer are deer, their antlers are really a form of bone that has grown directly out of their foreheads. Reindeer are the only form of deer in which both sexes have antlers. Also, like other deer, reindeer shed their antlers in the spring and grow new ones. Thus, where there are a lot of reindeer, antler material is abundant.

Paleoarchaeologists find that people using the Perigordian industry some 34,000 years ago infrequently produced bone or ivory tools, but the frequency increased with the long-term development of the industry. Around the same time, another industry, known as the Aurignacian, had a much greater emphasis on bone and also utilized reindeer antler as an important raw material. Bone points (objects that appear to be arrowheads or spear points) were especially prominent and underwent steady development throughout the Aurignacian. Farther north, and

slightly later, a tool industry called the Gravettian developed. It relied as heavily on mammoth bone as the Aurignacian did on reindeer bone and antler.

The Solutrean tool industry that started in France and Spain about 21,000 BP was marked not so much by increased use of bone or antler, but by decreased use of stone. Needles made from bone were common, suggesting that a lot of sewing was going on.

The real jump from stone to bone (and other materials) came with the next industry, the Magdalenian, which started around 17,000 BP in France and northern Europe. This toolkit was characterized by bone harpoons, some with one and some with two rows of barbs. Other bone tools that were common included not only needles, but also awls, polishers, and spear throwers. A mysterious tool made from reindeer antler, called the *baton de commandement*, may have been a spear straightener.

Following the Magdalenian were several industries that correspond roughly to what is sometimes called the Middle Stone Age or the Mesolithic. Essentially, this was a transition period of about 5000 years to the Neolithic. These industries utilized microlithic stone tools and continued to use the variety of bone and antler tools that had also been made in the Magdalenian.

When cattle were domesticated as part of the Agricultural Revolution, cattle horn came into enough of a supply to be useful as well. With the coming of metal, bone and horn ceased to have a real place in technology. Today, although we still use wood and stone for various purposes, spare bone and horn is either discarded, ground up for use as fertilizer, or otherwise processed into another material. Teeth (ivory) are still valued, but concerns about endangered species have curtailed their use — and ivory has always been in comparatively short supply. Considerable Stone Age technology persisted in the far north until quite recently, including the use of whale bone and walrus or narwhal ivory. Objects carved from these substances, as well as the similar objects called scrimshaw carved by 19th century whalers, are valued today. Modern versions continue to be made (often faked as antiques) for decoration.

II Food & agriculture

Grinding stones in the Near East are probably used for processing the seeds of wild grasses, a prelude to plant domestication. *See also* 24,000 BCE FOOD; 11,000 BCE FOOD.

I Tools

Stone arrowheads are used (Spain). *See also* 25,000 BCE TOOL.

15,000 BCE

Communication

The Magdalenian culture, which ranges from northeastern Spain deep into central Europe, produces, in addition to the famous cave paintings of its southern portion, such as those at Lascaux, France, many engravings on bone, antler, and slate, including animal figures and abstracted female humans. *See also*

20,000 BCE COMM; 12,000 BCE COMM.

Materials

Rope is in use, according to evidence at Lascaux Cave (France). *See also* 12,000 BCE COMM.

Mathematics

From this time until 10,000 BCE, people inhabiting caves in the Middle East use notches in bones to record sequences of numbers. These are

thought to function primarily as lunar calendars (Israel and Jordan). *See also* 30,000 BCE MATH.

I Tools

The spear thrower (sometimes called the atlatl, its Aztec name) is invented.

The Magdalenian tool industry in Europe over the next 3500 years produces fine harpoons with both single and double rows of barbs, needles,

The first machines

Simple machines are devices that do nothing but change the direction, duration, or size of a force. The single pulley is the dullest simple machine, changing only direction. Most other simple machines are variations on the lever or the inclined plane — for example, the wheel and axle (or crank handle) is a rotary lever, the wedge is a pair of inclined planes, and the screw is a helical inclined plane.

Which simple machines were used by early humans? The earliest stone tool is a form of wedge, as are most stone tools. The handle of an axe or hammer is a form of lever, so hafted axe heads (in use by the middle of the Old Stone Age) qualify as simple machines. Other early evidence of thoughtful use of simple machines before Neolithic times is hard to come by. However, it is

easy to believe, although difficult to prove, that early humans used levers to turn or lift heavy objects.

An important application of the lever from about 15,000 BP is the spear thrower, or atlatl, an extension of the human arm used to translate a small motion near the shoulder into a large motion near the end of the spear thrower. Since the time of the motion does not change while the length of the motion increases, the result is a higher velocity for the spear thrown. The higher velocity gives the spear greater momentum, useful either for distance or for penetrating power.

Perhaps the most sophisticated simple machine is the compound pulley, in which mechanical advantage is cleverly obtained with no visible levers. The compound pulley appears to have been invented in Hellenistic times, about 200 BCE.

awl, spear throwers, and points, all made from bone or antler, as well as microliths and unretouched flake points. *See also* 17,000 BCE TOOL; 7500 BCE TOOL.

A tool made of antler (usually from reindeer), known today as the *batône de commandement*, a part of the main body and two major branches of the antler with a hole bored near their junction, becomes common. It is not clear today what the baton was used for, although shaft straighteners for spears and softeners for leather thongs are among the uses that have been suggested. The name *batône de commandement* comes from the idea that the tool may have been a symbol of authority. Often designs or illustrations are carved into the baton.

13,000 BCE

► Anthropology

At Mezhirich (Ukraine) storage pits near mammoth-bone dwellings are distributed unequally, suggesting that some family units had more resources than others, the first

known evidence of a social hierarchy.

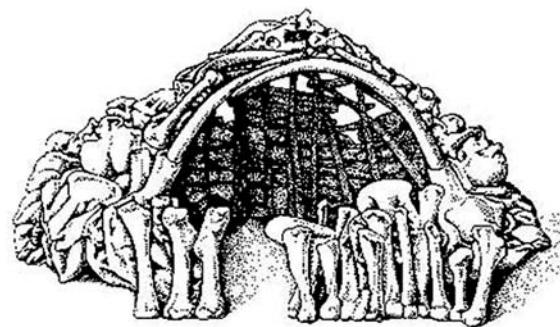
↳ Communication

The famous polychrome red-and-black paintings of standing and lying bison are made on the ceiling of the Altamira Cave. Radiocarbon dating gives 16,450 to 12,450 years BCE for the charcoal used in the paintings. *See also* 20,000 BCE COMM; 12,000 BCE COMM.

The first known artifact with a map on it is made on bone at Mezhirich. The map appears to show the region immediately around the site at which it was found. *See also* 6200 BCE COMM.

■ Construction

At Mezhirich, huts made from mammoth bones use specific bones for specific parts of the dwelling. Hundreds of bones are used to make the frame, and the weight of the bones alone is estimated at 22 tons. In 1992 workers found that a hut had an underground entrance, about 3000 to 5000 years prior to any other known underground entrances. *See also* 26,000 BCE CONS; 11,500 BCE CONS.



MAMMOTH-BONE DWELLING The hut made from mammoth bones, shown here in a drawing, would have been covered with skins. During the Ice Age, mammoth bones were more available than trees in the frozen north of what is now Ukraine.

■ Food & agriculture

According to DNA evidence, the dog is domesticated from wolves in East Asia. The same sort of evidence suggests that all modern dogs are descended from these early domesticated canines and that dogs were brought to the New World by humans, not domesticated from New World wolves. *See also* 18,000 BCE FOOD; 12,000 BCE FOOD.

At Mezhirich, as at other sites from the same region and time, pits dug into what was then permafrost are used to store food, the first known

form of cold storage. *See also* 13,000 BCE FOOD.

❖ Materials

Figurines are shown wearing such clothing as skirts, aprons, headdresses, and parkas. *See also* 19,000 BCE MATR; 6000 BCE MATR.

→ Transportation

At Mezhirich, marine shells from the Black Sea, some 580 km (360 mi) to the south, demonstrate that the people who lived there were part of an extensive trade network. *See also* 11,000 BCE TRAN.

Trade with distant peoples

Early evidence of long-distance trade includes the presence far inland of marine seashells in the 14th century BCE and obsidian imported into Greece as early as the 11th century BCE from the island of Melos. Six thousand years later there is increasingly good evidence of trade between Mesopotamia and ports along the Persian Gulf and the west coast of the Indian subcontinent, along with the island of Ceylon. In another thousand years, by the third millennium BCE, Egypt was actively involved in trade in the eastern Mediterranean.

Early shipping stayed close to land in the eastern Mediterranean. Gradually, however, explorers from Europe moved throughout the Mediterranean and into coastal Atlantic waters along the western parts of Europe and northern Africa. Egyptian pharaohs sent expeditions down the eastern coast of Africa as well, while regular trade developed across parts of the Indian Ocean between Arabia and Africa and between Mesopotamia and India. Some of the Indian Ocean voyages may have been across the open sea, helped by reliable monsoon winds.

Chinese ships and navigation tools were more advanced than any others on Earth until at least the European Renaissance, so Chinese navigators also are presumed to have ventured across open seas from early on. The most notable voyage that is well-documented, however, comes in the 15th century CE, much later than the period of early navigation.

12,000 BCE

Communication

People in southwestern Europe make many of the most famous cave paintings and sculptures, such as those at Lascaux and Altamira, showing animals primarily. Paintings and engravings are also made in the cave Les Trois Frères (France). See also 13,000 BCE COMM.

Food & agriculture

The domesticated dog is known in the Middle East. Earliest known remains of domestic dogs are from the Zarsian site at Palegawra (Iraq). See also 13,000 BCE FOOD; 8400 BCE FOOD.

11,500 BCE

Construction

People in Abu Hureyra in the Euphrates River Valley (Syria), who subsist primarily on wild grasses and gazelles, build pit houses that are partially dug into the soil, but that have wooden uprights supporting reed roofs. See also 13,000 BCE CONS.

Tools

At Blackwater Draw in New Mexico (the first site recognized), and across the entire western part of North America, the big-game hunters we call the Clovis culture leave behind their characteristic points. Their stone and bone weapons are found associated with the megafauna (large ani-

mals) of the time, including mammoth, large bison, large horses, and giant turtles. One popular theory to account for the extinction of the megafauna is that the Clovis hunters exterminated them all. See also 8400 BCE TOOL.

11,000 BCE

Food & agriculture

In Abu Hureyra (Syria) scientists have found grains of cultivated rye dated by University College of London archaeobotanists Gordon Hillman and Susan Colledge to about this time, the earliest for any domesticated grain. See also 13,000 BCE FOOD; 10,000 BCE FOOD.

Tools

Wood or bone sickles set with tiny flints as cutting edges are in use. Wear patterns on those that have been preserved show that they are used for harvesting grain. See also 9000 BCE FOOD.

Transportation

Greek sailors are able to import obsidian from the island of Melos to the mainland, demonstrating that they possess some form of boat. See also 13,000 BCE TRAN.

10,000 BCE

Construction

Houses of sun-dried brick held together without mortar are built in Jericho (West Bank). See also 13,000 BCE CONS; 8000 BCE CONS.

Food & agriculture

Flax is harvested, possibly for food, by people living near lakes (Switzerland). Domestic flax was probably obtained several

thousand years later from the wild flax that grows around the Mediterranean. See also 11,000 BCE FOOD; 7000 BCE FOOD.

Materials

The first known pottery is made by the preagricultural Jomon culture, the second wave of immigrants to settle in Japan. See also 24,000 BCE MATR; 9200 BCE MATR.

9500 BCE

Food & agriculture

Goats and sheep are domesticated in Ali Kosh, Persia (Iran) and Afghanistan. See also 9000 BCE FOOD.

Mathematics

People of the Azilian tool making industry (France) in the Middle Stone Age paint geometric designs on pebbles. See also 25,000 BCE MATH.

9200 BCE

Materials

Early rice farmers at the Xianrendong and Wangdong caves (China) begin to make pottery. See also 10,000 BCE MATR; 7000 BCE MATR.

9000 BCE

Food & agriculture

About this time the mammoth becomes extinct on the continents of Eurasia and North America. Pygmy mammoth populations survive on islands. See also 2000 BCE FOOD.

Einkorn wheat is domesticated by people we now call Natufians who live at the north end of the Dead Sea (Israel). See also 7000 BCE FOOD.

What caused the Agricultural Revolution?

The Agricultural Revolution was discovered, named, and studied in the 1920s through the 1940s. In 1950 it was renamed the Neolithic Revolution by (Vere) Gordon Childe, who is often considered the main early worker in the study of the Agricultural Revolution.

The Neolithic adoption of a new way of life was easy to explain before 1950. The theory was that farming is better than hunting and gathering; so when people found out about farming they stopped hunting and gathering and settled down in villages. Many scientists today, however, believe that farming is not better than hunting and gathering. People knew how to farm for a long time before they bothered to make it a main way of life. There is some evidence that people had known for at least 20,000 years that a single seed planted in the ground could grow into a plant with many seeds on it. Many people who knew how to farm never stopped hunting or gathering. Careful studies have shown that hunter-gatherers have more leisure and a better diet than farmers. People also settled down into permanent villages before they started farming.

Also, it seems very odd that the Agricultural Revolution occurred at quite close to the same time in the Near East, in Southeast Asia, in what is now Mexico, in South America, and in what is now China. Thus, a different explanation for the Agricultural or Neolithic Revolution was required, and many archaeologists have offered their opinions. Here are some of the more popular theories as well as one or two idiosyncratic ideas.

- *There Were Too Many People.* Population pressure caused local environments to become exhausted, and people had to find new sources of food. Diminishing resources caused by population growth finally forced people to do the hard work of planting and harvesting. To replace lost game, people began to breed their own animals for meat and fiber (with milk as a side benefit). This theory does not explain why some low-density populations clearly started farming before the numbers grew (as in highland Mexico). Something else must be involved in this case. All in all, there is less evidence to support high populations before the Agricultural Revolution than there is reason to believe that populations grew rapidly after it.
- *The Climate Changed.* Childe thought that a drier climate induced the Agricultural Revolution in the Middle East by reducing the availability of game and wild food plants. People had to move to oases, where domestication was essential for survival. This idea ran afoul of subsequent studies showing that the Middle Eastern climate did not become drier at the right time. There are other climate-change theories. When the ice caps retreated, for example, people were forced to abandon their reliance on reindeer and mammoths, creatures of the edge of the ice and the tundra.

With that major resource gone, some other source of food needed to be found. Similarly, the rise in sea level that accompanied the melting of the glaciers caused people in Southeast Asia to live on less land, resulting in the invention of agriculture there. The problem with the end-of-the-Ice-Age theory is that 1) the Ice Age ended 5000 years too soon for the Agricultural Revolution; and 2) it was not the people living near the edge of the ice or tundra who first started farming.

- *People Moved to Town.* One good reason for calling the change the Neolithic Revolution is that more than farming was involved. About a thousand years before agriculture started, people, especially those dependent on trade or on the storage and processing of wild grass seeds (such as wheat), began to live in permanent communities. Even if the region as a whole still had good food resources, the immediate vicinity of such communities would soon run short of both wild grasses and game. Domestication of plants and animals saved village life. The problem here is showing why people settled down.
- *Plants Grow in Garbage.* Plant remains tossed out in the garbage by people who had settled down sprouted. This produced new crops from the discarded materials, crops that could be easily harvested. People noticed this and developed the systematic way of throwing out parts of plants that we today term agriculture. Again, the problem is explaining why people lived in one place, near piles of garbage.
- *Society Became Complex.* The longer people were around, the more they developed complex societies that included traders (for which there is good evidence), specialists of all kinds, and people in charge. Such a society, with its division of labor and the need to have wealth that can be accumulated (by the people in charge), is forced into farming. Of course, some present-day or recent hunter-gatherer societies, such as the Native Americans of the northwest coast, developed complex societies without farming — but they had salmon or some similar resource so they did not need to farm.
- *It's What to Do in the Off-Season.* Hunting and gathering, like farming, are seasonal. The seasons of good hunting and gathering often do not cover the whole year. During the time when not much else is going on, people can improve their food supply by planting crops. Crops that would be harvested after the good gathering season and before the good hunting season would presumably be favored. This fails to explain why people did not farm earlier or why so many started farming in such a short time period. A variation of this concept is that people engaged in hunting and gathering inevitably learn a lot about animals and plants. When they have learned enough, they see that it would be easier to grow their own than to go out and hunt for them.

(continued on next page)

The problem with this theory is the studies that show that even in marginal environments, such as today's Kalahari Desert, it is easier and healthier to hunt for animals and plants than it is to grow them.

- *It Did Not Happen.* The last refuge of the historian or archaeologist faced with a major shift in society is to say that the change started much earlier, went on much longer, and lacks any moment in time that can be singled out. In this view, people replaced hunting and gathering with farming over tens of thousands of years. Even if this were true, which many would disagree with, it would not explain why people made such a change.
- *It Just Happened.* People did not set out to domesticate wheat or goats. Harvesting wheat over a period of years changed the nature of the wheat, since the seeds left behind by stone sickles remained on the plants that held on tightly to their seeds. Evolution then produced fields of wheat where most of the wheat clung tightly to the seeds. Such seeds were not good at producing next year's crop. As a result, people were forced to help the wheat by planting

some of the seeds. Similarly, hunters killing larger goats produced an evolutionary shift to smaller goats. It became necessary to take steps to breed these smaller goats to produce enough meat. Domestication was the inevitable result of the farming and hunting practices of the early Neolithic. This theory is fairly reasonable for wheat, but not much good for peas and lentils, which seem to have been domesticated about the same time. There are logical gaps that are hard to fill in for the explanation of animal domestication.

- *Space Creatures Started It.* The proliferation of theories and the flaws in all of them sometimes makes one think that it would be just as well to contend that extraterrestrial beings, thought by people of the early Neolithic to be gods, went from place to place around Earth over a period from about 9000 to 5000 BCE teaching people to stop hunting and gathering and to start farming. This theory is essentially the one espoused in most traditional farming societies — that is, they have legends that tell them that the gods taught them how to raise crops. It has recently resurfaced in popular literature, although not held by any working archaeologist.

The chicken is domesticated in southern Asia (Thailand). *See also* 10,000 BCE FOOD; 2500 BCE FOOD.

8750 BCE

Food & agriculture
Pumpkins and related squash are domesticated in what is now Mexico and Central America. *See also* 9000 BCE FOOD; 5300 BCE FOOD.

8500 BCE

Tools
Arrow shafts are left at a site at Stellmoor, Germany, the earliest direct evidence of the bow and arrow known today. *See also* 25,000 BCE TOOL; 3500 BCE TOOL.

8400 BCE

Food & agriculture
The dog is the only domesticated animal in North America at this time, according to

evidence from Jaguar Cave (Idaho), a situation that persists until at least 1500 BCE. *See also* 10,000 BCE FOOD.

I Tools

Stone tools known as Folsom points and probably used as arrowheads begin to be manufactured in North America by Native Americans. Among the earliest examples known are those from Blackwater Draw (New Mexico), although the points are named for the site of first discovery, Folsom (New Mexico) and best known from the Lindenmeier (Colorado) site. *See also* 11,500 BCE TOOL.

8000 BCE

Communication

Chinese at Jiahu (Henan Province) carve symbols into tortoise shells, which are then left in graves. According to Garman Harbottle of the State University of New York at Stony Brook, the symbols are precursors of Chinese ideo-

graphic writing. If so, this is the earliest form of writing known.

¶ Construction

The oldest wall known is built in Jericho (West Bank) from boulders set in place without mortar. It is more than 3.6 m (12 ft) high and is 2 m (6 ft 6 in.) thick at the base. *See also* 4200 BCE CONS.

People living in Jericho known as the Pre-Pottery Neolithic build dome-shaped houses from sun-baked brick that is formed entirely by hand (without molds). *See also* 10,000 BCE CONS; 7000 BCE CONS.

Tell Mureybit (Syria) contains stone houses, although the villagers are hunters, not farmers. *See also* 10,000 BCE CONS; 4500 BCE CONS.

II Food & agriculture

Potatoes are domesticated in the Andean Highlands (Peru). *See also* 8750 BCE FOOD; 7400 BCE FOOD.

The banana and the taro root

are domesticated in the highlands of New Guinea.

Beer is brewed in Mesopotamia. *See also* 6000 BCE FOOD.

Floodwater agriculture is used in the Nile valley and in southwestern Asia. *See also* 6000 BCE FOOD.

◊ Materials

Although it is impossible to be certain, it appears that copper is used occasionally by this time; it is worked like a soft stone, not cast. *See also* 6400 BCE MATR.

Σ Mathematics

The first forms of fired clay tokens are being used by Neolithic people to record the products of farming, such as jars of oil and measures of grain, at sites in what are now Syria and Iran. Tokens are believed to have evolved into the separate ideas of number and written word over the next 5000 years. At a few sites tokens continue to be used until about 1500 BCE.

Building with brick and stone

The principal early building material of civilization was brick, most often unfired. Even thousands of years before civilization, builders in Jericho used sun-dried mud brick, sometimes called pisé. Adobe is a somewhat better sun-dried brick made from clay reinforced with straw. Adobe brick was also commonly used in Old World cities. Fired brick was usually reserved for public buildings or for facing structures of sun-dried brick.

Brick, especially unfired, weathers away quickly. As a result, the best known architecture of ancient times was of stone, the material of choice for temples, palaces, and other large public buildings. Stonehenge and the limestone pyramids and sphinx of Egypt offer the principal images of truly ancient structures, followed in our minds (although much later in fact) by the marble temples of Greece, the marble amphitheaters and baths of the Roman Empire, and yet more limestone-faced pyramids in Mesoamerica.

Simple structures of giant stones arranged in a pattern are called megaliths. The megaliths that were erected across the western European continent, on Great Britain, and on Malta include tombs (called dolmens), temples, and observatories. Similar groups of erect giant stones were constructed as tombs in India and other places in Asia thousands of years later. From a technological point of view, quarrying, moving, and erecting the stones, which often weighed 40 tons or more, seemed to be beyond the abilities of Neolithic or Bronze Age farmers. Diffusionist theories of the past called for Minoan or Egyptian engineers, but it is now clear that the megalith builders came earlier than the Minoans and that some of the monuments predate Egyptian engineering. The megalith builders used fire to make cracks in stone, which they then split using the power of swelling of wet wood along with progressively larger wedges. Lacking wheeled vehicles, it is thought that they simply dragged the stones, perhaps with the aid of sledges, or sometimes floated them partway on rafts. An inclined plane and a predug hole helped set the stones upright. For the most part, these were the same techniques used by the

Egyptians in building the pyramids, but the megalith builders probably discovered the methods independently.

The rulers of Mesopotamia did not have stones to work with. Nevertheless, they built tall structures reaching toward the heavens. Called ziggurats, these temple towers were made from brick, often cemented together with tar (bitumen) or tar mixed with sand and gravel (mastic). In the absence of other, cheaper materials, molten lead could have been used as mortar. Sun-dried brick and adobe were usually cemented with more of the same mud that had been used to make the bricks. If limestone or gypsum was present, it could have been heated and then ground to form lime plaster or cement that hardens when water is added, similar to the mortar used by today's masons. Lime plaster was used in ancient Egypt and by most early civilizations of both the Old and New Worlds.

Egyptian engineers and early temple builders in South America often dressed stones so that they fit tightly together, shaping them so that gravity held them in place. The megalith builders who put up the last stage at Stonehenge used a version of this method, quarrying the stones so that they could dovetail mortises and tenons, forming rigid joints. Greek architects and early Romans also used iron cramps (right-angled bars) to hold stones in place.

Sometime around the third century BCE the Romans began to use volcanic ash found in Italy, notably huge beds near Puteoli (Pozzuoli) on the Bay of Naples. These had been produced during eruptions of Mt. Vesuvius. Ground ash could be added to lime mortar to produce cement as hard as rock, cement that hardened even underwater. The silica in the ash combined with the calcium carbonate of the lime and with the water. By the early Roman Empire the new form of cement, mixed with sand and rock to form concrete, had become the principal building material, almost as cheap as brick and often better than stone. Although the Roman builders never abandoned stone and brick completely, they used more and more concrete and less and less stone and brick. Often the stone or brick ceased to have a structural purpose and was used as ornamentation for the concrete walls of buildings.

7500 BCE

■ Construction

The large village — population 10,000 — of Çatalhöyük (Turkey) is started, with mud brick houses crowded together. People enter the dwellings from a hole in the roof. Families live for several generations in a house, burying the dead under the floors. Interior walls are covered with murals.

When a family line dies out, the old house is filled in from the top, and a new house is built on top of the old. *See also* 80,000 BCE COMM; 6000 BCE CONS.

❖ Materials

The Maglemosian culture of the northern European plain, in addition to stone axes and microliths, uses wooden canoes with paddles to carry out a fishing industry that

involves both nets and fishhooks. Many of these organic items (including wooden fishhooks and harpoons) are preserved in bogs and other wet sites. *See also* 120,000 BCE MATR; 4300 BCE TRAN.

❖ Tools

The Sauveterrian tool industry (inland France) produces some of the smallest microliths, especially microblades with two sharpened

edges. *See also* 15,000 BCE TOOL.

7400 BCE

❖ Food & agriculture

Chiles (peppers) are grown in the Andean highlands (Peru). Since the chile is a tropical plant, it was probably domesticated previously in the lowlands. *See also* 8000 BCE FOOD; 6400 BCE FOOD.

7000 BCE

Construction

A group living in Jericho (West Bank) build rectangular houses from sun-baked brick and mortar formed by heating limestone and mixing the product with sand and water. They also use the transformed lime (known as “burned lime” to archaeologists) to plaster

walls and floors. *See also* 8000 BCE CONS; 3000 BCE CONS.

The Yangshao people along the Huang He (Yellow River) in China live in underground, circular mud-and-timber huts in communities that feature large kilns for making painted pottery. *See also* 23,000 BCE CONS.

Food & agriculture

Durum wheat is cultivated in Anatolia (Turkey). *See also* 9000 BCE FOOD; 6000 BCE FOOD.

Sugar cane is grown in New Guinea. Flax is cultivated in southwestern Asia. *See also* 10,000 BCE FOOD.

The pig is domesticated according to evidence found at Cayönü (Turkey). Yams,

bananas, and coconuts are grown in southeastern Asia (Indonesia). Cattle are domesticated in southeastern Anatolia. The water buffalo is domesticated in eastern Asia and China. *See also* 6000 BCE FOOD.

Materials

People at various sites in the Near East and southeast Asia (Burma to Vietnam) begin to

Irrigation and the rise of civilization

After the Agricultural Revolution, farmers quickly learned the importance of water and sunlight to crops. Sunlight can be obtained by burning away part of the forest, which is the method used in most places with abundant water to this day. Often, however, broad reaches of land already exist with no forest cover; but this is because the region lacks sufficient water. If a farmer can get water to fields in such sunny lands, the resulting crops are prolific.

Sometimes a river runs through such land. The river obtains its water somewhere that is rainy, usually in high mountains unsuitable for farming. It then carries the water through desert or semi-desert as it flows to the sea. Rivers of this type include the Nile, Tigris, Euphrates, Hwang Ho (Yellow River), Indus, and about 50 waterways in Peru that run from the Andes to the Pacific. Merely listing the rivers suggests that there is a connection between rivers running through dry lands and the development of civilization, for these are the rivers of Egypt, Sumer, China, Harappa, and the Chavín, virtually all of the earliest civilizations known.

The connection between rivers in deserts and civilization is thought to be irrigation. The political structure necessary to organize people for canal digging and fair use of river water for farming is also the political structure that supports other types of construction, city planning, state religion, education, and a class with the leisure to pursue mathematics, science, and philosophy. This “theory of the hydraulic society” stems from such thinkers as Friedrich Engels, Karl Marx, Max Weber, and Karl Wittfogel. While not everyone agrees that irrigation caused the state (some think that class divisions started first, enabling irrigation systems), even most critics of the hydraulic theory think that it applies to some degree to the civilizations listed in the previous paragraph. It especially seems to apply to Sumer, which was, after all, the first civilization. Although other civilizations seem to have independent origins, there is a strong possibility that they at least heard

rumors that something brand new was taking place in Mesopotamia.

In Mesopotamia streams were at a low level during the fall planting season, requiring very deep ditches for irrigation. When the high water arrived in the spring, it not only irrigated the plants, it also laid down a lot of silt in the canals, so the deep digging needed to be repeated. Both maintaining and building the system required organization and that seemed to mandate state control.

Where the hydraulic theory seems to break down is in civilizations such as the Olmec and early Maya, civilizations that developed in regions where a lot of water falls from the skies on a regular basis. In the past few years, however, aerial studies have shown that the Maya did possess large irrigation systems. Such systems were needed because most of the rain that fell over Maya sites immediately passed deep into the soil and underlying rock. There were no large rivers in Mayaland, but there were sinkholes filled with water and regular rain. Combining these resources required the large irrigation works that are called for in the hydraulic theory.

The Olmec civilization presents a tougher problem. One careful study, by William Rathje, focuses on the lack of hard rock and obsidian in the lowland rain forests of eastern Mexico, where the Olmec civilization began. Rathje has proposed that the state must have arisen there to facilitate long-distance trade, a recognized part of Olmec life.

However, if you return to the main early civilizations, it is hard to find any but the Olmec not heavily involved with irrigation right from the start. Even if war, classes, or population growth came first, large-scale irrigation requires record keeping, organization, different classes of workers, central planning, foresight, and so forth — in short, civilization and the state.

Unfortunately for most civilizations in arid regions, irrigation from a river also contains the seeds of destruction for the civilization (see the essay “Salt and the fall of civilization”).

fire clay pottery in kilns. *See also* 10,000 BCE MATR.

The oldest known woven mats are made in Beidha (Jordan). Basketry probably began much earlier.

6500 BCE

❖ Materials

Small lead beads are produced at Çatalhöyük (Turkey), but most likely the smelter failed to recognize that lead was a specific metal. *See also* 8000 BCE MATR.

→ Transportation

Wooden sledges for travel over snow are in use in what is now Finland. *See also* 5000 BCE TRAN.

6400 BCE

❖ Food & agriculture

Haricot beans (the common green and dried beans) and lima beans are grown in the Andean highlands (Peru), but since they are tropical plants they were probably domesticated previously in the lowlands. *See also* 7400 BCE FOOD; 5600 BCE FOOD.

❖ Materials

The first definitely known use of copper occurs in what is now Turkey. About this time people learn that copper can be melted and cast. *See also* 8000 BCE MATR; 5000 BCE MATR.

6200 BCE

← Communication

A town plan for Çatalhöyük is drawn, one of the earliest maps known. *See also* 13,000 BCE COMM; 2300 BCE COMM.

6000 BCE

❖ Archaeology

People settle the island of Crete. *See also* 2000 BCE ARCH.

❖ Construction

Various buildings in Anatolia (Turkey) are rectilinear with several rooms, some with paintings on the walls. Internal furniture includes benches and platforms made from cattle horns and plaster. *See also* 7500 BCE CONS.

❖ Food & agriculture

Modern-type domesticated bread wheat and lentils are cultivated in southwestern Asia. *See also* 7000 BCE FOOD; 5000 BCE FOOD.

Bulrush millet is cultivated in northern Africa (southern Algeria). Finger millet is cultivated in northern Africa (Ethiopia).

Irrigation based on canals is in use in Mesopotamia. *See also* 8000 BCE FOOD; 2400 BCE FOOD.

It is believed that wine making may have started in northern Mesopotamia (now northern Iran and Iraq) or in the Levant. *See also* 8000 BCE FOOD.

Peaches are grown in central China. Citrus fruit is cultivated in southeast Asia (Indonesia).

Genetic studies indicate that cattle have become domesticated in Africa as well as in Anatolia. *See also* 7000 BCE FOOD.

❖ Materials

Weaving of cloth is known in Anatolia (Turkey). The first known samples of cloth are from the early city Çatalhöyük. *See also* 7000 BCE MATR; 2000 BCE TOOL.

People in western Anatolia begin to make bricks in molds and then sun-dry the bricks; the same practice can be observed in Crete several hundred years later. *See also* 7000 BCE CONS.

5600 BCE

❖ Food & agriculture

The grain quinoa is grown in the Andean highlands (Peru). *See also* 6400 BCE FOOD; 4400 BCE FOOD.

5400 BCE

→ Transportation

About this time the earliest known boat other than a dugout canoe is built at As-Sabiyah (Kuwait) on the Red Sea. It is based on a complex material comprised of bitumen mixed with fish oil, crushed coral, and other materials, combined with reeds. Evidence that the boat actually was seagoing consists of barnacles attached to the underside. The boat was later disassembled, stored, and forgotten in a stone building some 7000 years ago. *See also* 7500 BCE MATR.

5300 BCE

❖ Construction

People in the Balkeramik culture of the Middle Danube valley (and later central Europe), known for distinctive line-decorated pottery, live in long, rectangular timber houses with thatched roofs. Some houses are as large as 14 m (46 ft) long. *See also* 6000 BCE CONS.

❖ Food & agriculture

The avocado is grown in Mex-

ico and Central America. *See also* 8750 BCE FOOD.

❖ Materials

A well is built of wood at Kuckhoven (northwest Germany). Because of local conditions, the wood is preserved, and the well becomes the oldest known wooden structure. *See also* 120,000 BCE MATR.

5200 BCE

❖ Food & agriculture

Egyptians begin to practice agriculture in the lower Nile valley thousands of years after the Agricultural Revolution had come to other peoples in the Near East. *See also* 9000 BCE FOOD.

5000 BCE

★ Astronomy

Egyptians divide the night and day into 12 hours each.

❖ Construction

Early farmers in the delta of the Euphrates (Iraq) build houses of reeds that have been lashed together. *See also* 7000 BCE CONS.

❖ Food & agriculture

Date palms are cultivated in India. *See also* 6000 BCE FOOD.

Rice is cultivated in the Yangtze Delta of southwestern Asia (China). *See also* 4000 BCE FOOD.

The horse is domesticated for food purposes in Ukraine. *See also* 4000 BCE FOOD.

Tobacco is grown and used (probably chewed) in the Andes region of South America (Peru and Ecuador). *See also* 1493 MED.

❖ Materials

In Santarém on the floodplain of the Amazon in Brazil, people from a fishing culture make decorated red-brown pottery. The remains they leave are the oldest known pottery fragments in the Americas. *See also* 7000 BCE MATR.

In Egypt, weapons and implements made from native copper are occasionally deposited in graves. *See also* 6400 BCE MATR; 4700 BCE MATR.

I Tools

Axes in Mesopotamia are made with stone heads inserted between the cleft ends of a stick and bound into place. *See also* 7500 BCE TOOL; 3000 BCE TOOL.

→ Transportation

A cave painting in Zalavroug, near the White Sea (a large bay of the Arctic Ocean in Russia near Finland), depicts people walking on planks attached to their feet, an early form of skis. *See also* 6500 BCE TRAN.

4803 BCE

🌐 Earth science

Mt. Mazama (Oregon) erupts explosively, leaving behind the beautiful Crater Lake and Native American legends of an exploding mountain. *See also* 79 CE EAR.

4700 BCE

🏗 Construction

Megalith structures consisting of large stones arranged over graves are built (Ireland and along the Atlantic coast of France). *See also* 3000 BCE CONS.

❖ Materials

A large copper factory for



5600 BCE FOOD; 3500 BCE FOOD.

4300 BCE

→ Transportation

Oak canoes are used on the Seine at what is now Paris, France. Workers will discover three such canoes while digging foundations for a new building in Paris in 1992. The largest of the canoes is nearly 5 m (16 ft) long. *See also* 7500 BCE MATR.

4200 BCE

🏗 Construction

The Danish village of Köln-Lindenthal, thought to be a typical northern European community of the time, which has been settled and abandoned at least seven times over a period of 370 years, is rebuilt for the last time, but for the first time with a tall palisade and earth wall around it, suggesting an increase of warfare at that time. *See also* 8000 BCE CONS; 3000 BCE CONS.

❖ Materials

The Egyptians mine copper ores and smelt them. *See also* 4700 BCE MATR; 3800 BCE MATR.

assembly line production of implements and ingots is constructed at Khirbat Hamra Ifadan (southern Jordan) with a dozen smelting furnaces and more than 80 rooms, court-yards, and other spaces devoted to production. Copper is refined here and tools from this plant circulate throughout the Middle East. The plant operates until about 2200 BCE. *See also* 5000 BCE MATR.

made from a copper ore such as azurite or malachite and then heating the combination to a very high (for that time) temperature; the result is a blue-coated glass. The faience is used for the manufacture of beads and other small ornaments. Later the talc substrate will be replaced with a material made by fusing quartz sand and soda, perhaps the first artificial substance ever made. *See also* 3000 BCE MATR.

4500 BCE

🏗 Construction

Stone is used to construct buildings in Guernsey, an island in the English Channel. *See also* 8000 BCE CONS; 3000 BCE CONS.

❖ Materials

A material now known as “Egyptian faience,” essentially an imitation lapis lazuli, is made in Mesopotamia by covering the surface of a talc stone or soapstone with a powder

→ Transportation

Archaeological evidence suggests trade between Mesopotamia and port regions on the Indian Ocean. While this could have all been overland, it seems more likely to have been conducted in boats. *See also* 11,000 BCE TRAN.

4400 BCE

🍴 Food & agriculture

The guinea pig is domesticated for food in Peru. *See also*

4000 BCE

🏺 Archaeology

Uruk (Erech in the Old Testament and Warka to Arabs), perhaps the first great city, is founded in Mesopotamia (Iraq) on the banks of the Euphrates River. *See also* 3500 BCE ARCH.

Metals and early smelting

A few metals can be found in nature as elements, not compounds; these are called "native." Native gold is relatively common, especially small flakes separated by weathering and transport; it is segregated somewhat from other minerals by its high density. Native silver and copper are much rarer, although modern miners have sometimes found large masses of silver (hundreds of kilograms in the rarest instances). Copper is actually the most widely distributed native metal, often precipitating from its ores as a result of chemical reactions; but amounts in the native form are always small.

Native iron can rarely be found as a result of interactions between igneous rocks and coal seams, but some meteorites contain large masses of iron or an alloy of nickel and iron. The other native metals — arsenic, antimony, and bismuth — occur mostly in hydrothermal vents and are of little importance. Of the common native metals, only copper is hard enough to be useful, and it is only hard when compared with gold and silver. Nevertheless, the advantages of copper tools over stone, bone, and wooden tools were apparent to early humans, and native copper was probably used from near the beginning of Neolithic times.

Although native copper is hard to come by in large amounts, copper ores are quite common and some of them produce metal easily when burned in wood or charcoal fires.

Learning how to smelt copper vastly increased its supply in the early years of civilization. A Copper Age that lasted about 500 years in the Near East followed the discovery of copper smelting; it ended when bronze (copper alloyed with tin, or sometimes with other metals, ranging from silver and lead to arsenic), a better metal, was discovered. In parts of the world where copper ores were plentiful, but tin was rare, the Copper Age persisted until trade routes for tin or for finished bronze replaced copper with bronze. In Egypt, where tin cannot be found, copper hardened with arsenic was used until about 2000 BP.

While copper ores in small amounts are common worldwide, there are a few places where good copper ore in easily smelted form is abundant. For the ancient world, the island of Cyprus was the main supplier of copper — indeed our word *copper* derives from the name *Cyprus*. Cyprus not only had the ores, but as an island in the eastern Mediterranean, it was easily reached by ships from Egypt, Greece, and somewhat more distant Rome.

Tin was more of a problem. The only known large deposits of tin in the ancient world were in western Great Britain, an island like Cyprus, but in the Atlantic instead of the Mediterranean and far to the west of Egypt and Greece. Long trade routes for tin began by crossing the English Channel to Gaul (France) and continuing overland to Mediterranean ports such as Massalia (Marseilles) before loading goods onto sailing freighters. Such travel contributed to the high cost of tin, and therefore of bronze. When the Romans near the end of the republic occupied Britain,

an occupation that lasted for about 400 years, their main goal was probably control of the tin trade.

Bronze is a relatively strong and corrosion-resistant metal, but people in Antiquity also used the other main alloy of copper, brass. Today brass is known to be made from copper and zinc, but zinc was not discovered until the 13th century in India and not produced in the West until its rediscovery in 1746. However, as early as the 16th century some alchemists were aware that there was a metal at the heart of the mineral known by the ancients as *calamine* — recognized today as two different zinc-based compounds, zinc carbonate and zinc sulfate. The earliest brass was made by smelting copper ores or copper with calamine; according to one early source, brass smelting was first accomplished in Anatolia (Turkey) by a people called the Mossynoikoi. The earliest brass item known today dates from 20 CE.

Brass is as useful as bronze and more attractive; its golden shininess caused the ancients to consider it a form of precious metal. However, all the "brazen" items mentioned in the Bible were probably made from bronze, not brass. The words *bronze* and *brass* were used indiscriminately until recent times, and even today certain alloys of copper and zinc that should be called brasses are known as bronzes. Although zinc is more common than tin, lack of clear recognition of zinc may have contributed to its late arrival and rarity in early times. Today brass is more commonly used than bronze.

Another metal known from early times was the easily smelted and relatively common lead. It had many purposes, including those based on a property for which lead is often used today — it is denser (weighs more per unit of volume) than other inexpensive materials. Thus, one early and still common use for lead (by the Egyptians) was as a weight on fishing nets. From a mathematics problem in the Rhind Papyrus (c. 1650 BCE) we know that lead at that time was not very cheap. It had half the value of silver and a quarter that of gold.

Although iron was used sporadically when found in native form or in meteorites or made from easily smelted ores — one theory is that the earliest iron manufacture came as a byproduct of fires burned while obtaining red ochre to use as paint — it was not important for making weapons or utensils. The main reason is that when iron is smelted in the same way as copper or tin, the resulting metal is not in a form that is very strong or hard. The earliest iron samples from Egypt, however, are all of meteoric origin, according to chemical analysis.

Iron had been known for thousands of years before people living in what is now Armenia found that reheating and hammering produced a material vastly superior to copper or bronze for most purposes. Those who knew the secret of making iron weapons soon cut a great swathe through the Near East and the eastern Mediterranean, although they did not win all battles. By about 1200 BCE the "secret" was no longer a secret at all and the Iron Age had begun.

City life

Sometimes it seems that the only fashion in human society that has persisted throughout the past 6000 years has been the city. People since Sumer have left the farm or village and moved into town. If it were not for the steadily increasing human population, the countryside would have become barren long ago. In contrast, cities have grown from a few thousand to millions.

The primary cause for moving to the city is nearly always economic. People find that they can make money in cities; also, farms can only support so many people. A family farm may be able to carry members of three generations, but seldom can it support everyone or even every male in those three generations. Excess males must move out. If all the land is taken, the excess farmers must move to the city.

The earliest civilization, in Mesopotamia, consisted of small city-states, unified by Sargon of Akkadia after 1500 years of urban life. In Egypt the process was reversed; the first great city, Memphis, was founded after unification, about a thousand years after urbanization had struck Mesopotamia and hundreds of years before Sargon. About the time of Sargon a pair of great cities were built on the Indus River in what is now Pakistan, each laid out in the now familiar pattern of a rectangular grid. Early in the second millennium BCE, cities were also built at Knossos in Crete and in China by the earliest emperors. In the Americas, large cities did not appear until at least the first millennium BCE.

At its height, early in the first millennium CE, Rome was by far the greatest of all the cities of the Metal Ages. Although estimates vary, it seems likely that the population of Rome during the early centuries of the common era was about a million, double or four times that of other large cities of the time.

Communication

People in the Near East begin to use seals to identify property by stamping the seal into wet clay. *See also* 3000 BCE COMM.

Food & agriculture

Olives are cultivated in Crete.

Rice is cultivated in Indochina (Thailand), probably having spread from a center in the Yangtze Delta. *See also* 5000 BCE FOOD; 2000 BCE FOOD.

The ard, a primitive form of plow, is in use in China. Plows pulled by cattle are known in

northern Mesopotamia. *See also* 6000 BCE FOOD.

Maize, called corn in the United States, is domesticated in what is now the Tehuacán valley or nearby Oaxaca, Mexico. *See also* 7000 BCE FOOD.

Materials

The Egyptians and Sumerians smelt silver (make the metal from an ore). *See also* 4200 BCE MATR.

A standard kiln is developed in Mesopotamia. The fire is in a hearth below a perforated

separation from the kiln chamber where the pottery is held while it is being fired. *See also* 7000 BCE MATR.

Iron beads are used in what is now Cairo, Egypt, as evidenced by oxidized remains of a string of them. This is the earliest direct proof of human use of iron. *See also* 3500 BCE MATR.

Mathematics

The simple tokens that have been used for keeping numerical records since about 8000 BCE are first supplemented by complex tokens that have marks on them or that are in new and varied shapes (the earlier, unmarked tokens were almost all simple geometric shapes or representations of jars or animals). *See also* 8000 BCE MATH; 3700 BCE MATH.

A system of numeration begins to be used in Egypt.

Transportation

Egyptians build boats made from planks joined together. Previously, boats were dugout canoes and possibly rafts of reeds bound together or skins stretched over a framework. *See also* 4300 BCE TRAN.

Horses are being ridden in what is now Ukraine. *See also* 5000 BCE FOOD.

3800 BCE

Materials

Records from the court of Egyptian Pharaoh Snefru refer to copper mines on the Sinai Peninsula. *See also* 4700 BCE MATR; 3500 BCE MATR.

3700 BCE

Materials

The oldest known use of bronze

is in a rod found in the Egyptian pyramid of Meduin and probably deposited about this time. *See also* 3000 BCE MATR.

Mathematics

The first known example of a fired clay envelope used to hold counting tokens is left at a site called Farukhabad in what is now Iran. *See also* 4000 BCE MATH; 3500 BCE COMM.

3600 BCE

Materials

Farmers from the lowlands of Southeast Asia move to the Khorat Plateau in what is now northeast Thailand where they become expert potters and metallworkers, although the main business of the region is rice farming. *See also* 3800 BCE MATR.

3500 BCE

Archaeology

Sumer, the world's first civilization, flourishes on the banks of the lower Tigris and Euphrates rivers (called Mesopotamia, for "between the rivers") in what is now Iraq. It is formed from such city-states as Uruk, Ur, and Lagash, with no overall central government linking them. *See also* 4000 BCE ARCH; 2800 BCE ARCH.

The small provinces of Upper Egypt, called nomes, are united to form the single kingdom we call Upper Egypt. *See also* 3000 BCE ARCH.

Astronomy

A large — 22 m (72 ft) high, weighing more than 250 tons — standing stone, or menhir, known as the Grand Menhir of Locmariaquer, is erected in Brittany, probably for use in making astronomical observations.

Inventing and writing numbers

Virtually all numeration systems start as simple tallies, using single strokes to represent each additional unit — / for one, // for two, ///// for seven, and so forth. Evidence of such systems have been found as marks on bone dating from as early as 30,000 BCE and becoming common by 15,000 BCE. Studies of modern peoples with limited words for numbers — often just *one*, *two*, and *many* — show that they also used simple tallies, or at least concrete objects such as sticks, to show specific numbers greater than two. Thus, the tally system for representing numbers can exist even when language has not developed words for numbers. Linguistic evidence suggests that concrete words, such as *twin* for two people and *brace* for two dead birds, precede the concept of twoness in language. Yet each could have been indicated with two strokes or two sticks used as tallies.

In the Near East of Neolithic times the number language was a typical “one, two, many” system (as in our *monogamous*, *bigamous*, *polygamous* classification scheme), while tallies were used to represent specific numbers. The token system that is the ultimate ancestor of both cuneiform writing and the Roman alphabet was a later invention. Tokens are small bits of shaped clay that represent specific objects that are being counted. Tokens were gradually replaced by cuneiform writing. The first step was to mark the outside of a clay envelope in which tokens were kept with impressions of the tokens inside. After tokens had developed further, however, certain ones seem to have stood for sets instead of individual objects. By the late fourth millennium BCE, some tokens appear to have meant “ten sheep,” while others meant “one sheep.”

Thus, an envelope containing or marked with two of the ten-sheep tokens and three of the single-sheep tokens would indicate a flock of twenty-three sheep. At this point in time in most of Mesopotamia, however, a different type of token would indicate numbers or measures of a commodity different from sheep. Around this time in Uruk, traders were discovering that the same number could be used to mean ten sheep, ten bags of grain, or ten talents of copper. While this idea already existed for simple tallies, the extension to a more sophisticated numeration system represents the true creation of the abstract concept of number. Also, the tokens inside the envelope were discarded and only the markings were used to indicate numbers.

In Egypt, about 4000 BCE, the tallies were also grouped at ten, but ten of those tallies were regrouped at a hundred, and ten of the hundreds at a thousand. This seems more familiar, as it is closer to the system we use. The Greeks adapted the alphabet for numerals, with α for one, β for two, and so forth up to θ for nine

(with an extra symbol thrown in for six). The next nine letters (again with an extra symbol) meant ten through ninety, while the following nine (with an extra symbol) meant a hundred through nine hundred. Many other alphabet-using peoples followed the Greek example.

Roman numerals today are also alphabetical, but they did not originate as such. Early representations show that the X for ten originated in a manner similar to the use of a slanting stroke to connect four tally marks to indicate five — after each nine tallies, the Romans drew a slant mark across the tenth one, forming something similar to an X. This led to half an X for five, for which we use a V today. The L that we use for fifty has as its ancestor a symbol that was like an upside-down capital T. Number historian Karl Menninger has proposed that early Roman counters circled the tenth X to indicate a hundred or possibly to show a thousand; the left half of the circle remains as the C that is used to indicate a hundred. Similarly, the right half of the circled X became the D for five hundred. The whole symbol somehow became a thousand. Since the Latin words for hundred and thousand start with C and M, the connection with those letters was reinforced.

All of these systems are no longer in use, except for Roman numerals in some traditional uses. A better system that arose in India near the end of this period eventually replaced all other numeration systems. While the Indians used a derivative of the alphabet for words, the Greek idea of alphabetic numerals never reached them. Instead, they used horizontal tallies for one, two, three, and special symbols for four through nine. Originally, this system continued in a way similar to the Greek alphabet system, with special symbols for ten, twenty, and so forth. But around 600 CE (or some say as early as 200 BCE) the Indians started using place value, so that instead of writing the equivalent of $100 + 80 + 7$ they wrote symbols together, as we write 187, to mean the same thing. Only the first nine digits had to be used along with a symbol for zero, which they probably appropriated from astronomers' marking of empty places in large numbers. A famous inscription dated 870 CE contains the first zero that has survived. Arabs picked up the new system from the Indians and it was soon known as Arabic numerals in Europe. At the very end of the Middle Ages, the pope commanded that all Christians use what we now call Hindu-Arabic numeration.

The Mesopotamians had also invented a place-value system, but one based on sixty instead of ten. Although that did not survive to the present in its original form, it was used by astronomers and others in technical fields. From it we inherited sixty minutes to the hour and to the degree, as well as sixty seconds to the minute and the 360° circle.

It falls or is knocked down a few centuries after it is erected. *See also* 2750 BCE AST.

Communication

Complex fired clay counting tokens, including such geometric shapes as paraboloids as well as miniature tools, furniture, fruit, and even human figures, become common in the Near East. *See also* 4000 BCE MATH.

The first known examples of clay envelopes marked on the outside to tell what kind of or how many counting tokens are on the inside are left at sites in what is now Syria. *See also* 3700 BCE MATH.

Construction

A ziggurat in Ur (Iraq), 12 m (36 ft) high, shows that Sumerians are familiar with columns, domes, arches, and vaults. *See also* 2800 BCE CONS.

Energy

Candles are in use. *See also* 40,000 BCE ENER.

Food & agriculture

The llama and alpaca are domesticated (Peru). *See also* 4400 BCE FOOD; 3100 BCE FOOD.

Donkeys and mules are domesticated (Israel). *See also* 4000 BCE FOOD.

Wine is known, as evidenced by the residues found in a jar from Godin Tepe (Iran), an outpost of the Uruk (Iraq) urban center. *See also* 6000 BCE FOOD; 1500 BCE FOOD.

Materials

The Egyptians mine iron ore and smelt iron, using it mostly for ornamental or ceremonial purposes. *See also* 4000 BCE MATR.

People in Mesopotamia fire bricks in kilns, although sun-dried brick continues to be used for ordinary purposes. *See also* 6000 BCE MATR.

Europeans start producing metallic copper from copper pyrites by reducing the ore in wood or charcoal fires. *See also* 3800 BCE MATR.

Tools

A bowstave is left at Gwisho Springs (Zambia). It will become part of the earliest known pieces of direct evidence for the bow and arrow. Other evidence includes Mesolithic (Middle Stone Age) bows deposited in Scandinavia and arrow shafts from about 8500 BCE. *See also* 8500 BCE TOOL; 2000 BCE TOOL.

The first form of the potter's wheel, essentially a turntable that rotates only while being pushed and therefore used in start-stop fashion, is invented in Mesopotamia shortly before this time. *See also* 2500 BCE TOOL; 700 BCE TOOL.

Transportation

Sailing ships are used by Egyptians and Sumerians. *See also* 4000 BCE TRAN; 3100 BCE TRAN.

Wheeled vehicles are used in Mesopotamia as evinced by a pictograph from Uruk (Iraq). Next to the wheeled vehicle is a sledge that except for the wheels is exactly the same design. *See also* 6500 BCE TRAN; 3000 BCE TRAN.

3400 BCE

Transportation

A clay model found at Eridu in southern Mesopotamia is apparently of a boat made from skins, with holes and fittings in

the model that suggest that the model may originally have had a sail mounted on it. But clear evidence of sailing in Mesopotamia dates from much later. *See also* 3500 BCE TRAN.

3300 BCE

Archaeology

About this time a man, later to be known as the Iceman or as Ötzi, is killed in the Tyrolean Alps and his body and belongings preserved in the ice of a glacier. *See also* 13,000 BCE MATR; 3500 BCE MATR.

Communication

The Egyptians begin to write using hieroglyphic signs on papyrus, although the earliest hieroglyphs known are from an object called King Narmer's Palette, also from around this time. *See also* 4000 BCE COMM; 2900 BCE COMM.

Pictographs, some of which can be interpreted today, are used in horizontal strips on baked clay tablets in Sumeria. *See also* 3000 BCE COMM.

Food & agriculture

Cotton is grown in Mexico.

3114 BCE

Astronomy

The Maya Long Count calendar begins on the date we would record as August 13, 3114 BCE in the common Western calendar. It is not clear why this date was chosen.

3100 BCE

Food & agriculture

Domesticated peanuts are grown along the west coast of

South America (Peru). *See also* 2800 BCE FOOD.

Mathematics

Traders in Uruk (Iraq) begin to use symbols for abstract numbers that can represent the same amount of objects of any type. While numbers less than ten are represented by simple tallies, ten is a separate symbol that seems to derive from the token used for a small flock of ten sheep, while sixty is represented by a symbol that appears to be derived from a token representing a measure of grain. *See also* 3700 BCE MATH; 3000 BCE MATH.

Transportation

Rock drawings made shortly before this date in southern Egypt clearly show boats rigged with masts and broad square sails hung upon them. *See also* 3500 BCE TRAN.

3000 BCE

Archaeology

Semimythical ruler Menes of Upper Egypt succeeds in uniting his kingdom with Lower Egypt. *See also* 3500 BCE ARCH; 2475 BCE ARCH.

Astronomy

The Babylonians learn to predict eclipses. *See also* 2136 BCE AST.

Constellations of stars, such as Leo the Lion, are recognized. *See also* 1600 BCE AST.

Communication

Cuneiform writing is developed by the Sumerians as an outgrowth of their method of recording numbers. Clay tablets being used for pictographic writing in Sumer are turned on their sides to pro-

The invention of the wheel

"Man's first invention, and one of the most important in history, was the wheel . . ."

Jerome S. Meyer

The wheel symbolizes the first invention to the extent that the unnecessary rediscovery of any simple idea prompts the cliché "reinventing the wheel." But the wheel is far from the earliest invention. In the history of humanity, the wheel is recent. It is not known for sure what the first invention was, but our ancestors were making a vast array of tools for a couple of million years before anyone got around to the wheel.

The wheel was invented before it was used for transportation. The first wheels were potter's wheels. Before the potter's wheel, nature was essentially without wheels of any kind, as only a few microscopic animals, certainly unknown to early humans, possess anything like wheels for any purpose, especially not for transportation.

As with most inventions, the wheel not only had predecessors, it also required a number of related inventions before it could be useful. This concept is exploited for humor in Johnny Hart's comic strip *B.C.* An early inventor appears with his wheel, although he has failed to invent the cart, to build the road, or to domesticate the animal that would make his wheel of any use. Instead, he travels on it by standing on projecting axles and simply rolls along, downhill one presumes.

Before there were wheels, people dragged things across the ground. To help them in this task they first devised various forms of yokes, so that two or more persons or animals could work together to drag the same heavy load. A later invention, sleds of one form or another, could do a better job of dragging something that was too heavy to lift. One virtue of a sled is that it has nothing to catch on uneven surfaces as it is dragged. Where there was ice and snow, sleds — even in their highly individual form of skis (one sled for each foot) — are especially effective. Mesolithic rock carvings from Scandinavia show people skiing. A sled — also called a sledge — is clearly depicted in a pictograph dating from about 3500 BCE in Uruk in Mesopotamia. Just as clearly, one of the earliest wheeled vehicles, looking like a sled on wheels, is in the same drawing. Similarly, in one early cuneiform script the symbol for *sledge* existed first, a virtual pictogram of a sled with turned up runners. At a later date, the same symbol was used with wheels attached to mean *cart*. Thus, the cart was an easy step from the sled.

It is widely assumed that an immediate predecessor of the

wheel consisted of logs used as rollers for moving such heavy objects as the stones used in building the pyramids. There is no evidence for this. Early wheels are from Mesopotamia, where there were few logs in existence. The Mesopotamian wheels featured three planks cut and joined to make a wheel. Because of the grain in wood, wheels made by slicing a round section from a log tend to fall apart rapidly. Wheels can simply be attached to the sides of a cart with short axles on which the wheels turn independently, but early wheels were fixed to long axles that rotated as the cart moved.

The first use of the wheel was probably not utilitarian at all but ceremonial: Carts were used to transport effigies of deities and important people. Since important dead people were carried in the first such carts, it might be said that the hearse was invented before other forms of cart. The use of the cart for the transport of goods appeared about 1000 years after its invention.

Wheeled vehicles were used in war from early on. In Mesopotamia, four-wheeled wagons served as platforms for javelin throwers; two-wheeled war chariots also appeared first in Mesopotamia. Chariots were easily maneuverable because of the use of the much lighter spoked wheels, which were first known in Egypt about 2000 BCE.

The wheel spread from Mesopotamia quickly into Northwest Europe. Wheels also came into use around that time in India and China. In Egypt, the wheel became known about 2500 BCE. However, the use of the wheel remained unknown in large parts of the world including Southeast Asia, Africa south of the Sahara, and Australia and Polynesia, until much more recent times. Carts for transport disappeared subsequently in many areas around the beginning of the common era, including the Far and Middle East, because of the introduction of the camel for transport. The camel was far better suited for travel through desert areas than oxen drawing carts; oxen are slow and require abundant water.

Sleds and their close relatives continued in use in the Americas until after the arrival of the Europeans, although wheeled toys are known from pre-Columbian Mexico as early as 300 CE. In the mountains of Mexico and the Andes, goods were transported by carriers or pack llamas traveling along trails unusable by wheeled vehicles.

Historians are not certain when wheels became part of mechanical devices; however, such use is older than in transport, since the potter's wheel preceded the appearance of wheeled vehicles by a thousand years. Eventually, of course, the wheel found many uses in cogs, gears, pulleys, and all sort of machines.

duce a "page" that is in what modern computer users call "portrait" format instead of the horizontal "landscape" format. See also 1800 BCE COMM.

■ Construction

Farmers settled at Skara Brae in the Orkney Islands off Great Britain build stone houses with rounded corners, about 6 m (20 ft) square, with corbeled roofs completed with

whalebone rafters. Because of a lack of wood on the islands, furniture is also of stone, including beds with stone slabs, stone two-shelved dressers, and built-in stone storage cupboards. The beds

also feature stone posts and a canopy of leather. See also 4500 BCE CONS.

The first recorded architectural work of ancient Egypt is built under the orders of

Pharaoh Menes, a wall around his capital of Memphis. Originally brick coated with gypsum plaster, it is replaced in later times with stone. *See also* 8000 BCE CONS.

In Egypt and the Middle East (Jordan), dams are built to create reservoirs. *See also* 2500 BCE CONS.

🍴 Food & agriculture

The height of the annual flood of the Nile begins to be measured so that crop quotas can be based on the availability of water. Seeds and cattle (on loan) for plowing are provided to farmers by the pharaoh. *See also* 1850 BCE FOOD.

Cotton is cultivated and elephants are domesticated (India). *See also* 1800 BCE FOOD.

Camels are domesticated (Iran and Arabia). *See also* 3500 BCE FOOD; 2500 BCE FOOD.

Sanskrit sources refer to domestic cats in India. *See also* 18,000 BCE FOOD.

Plows in Mesopotamia are made with a piece of pointed timber formed into a share that cuts the soil and a sole that pushes soil aside, creating a deeper, wider furrow. *See also* 4000 BCE FOOD.

The bag press for extracting oil from olives, juice from grapes, and so forth, is invented in Egypt. Essentially, it is a fabric bag with two sticks arranged so that, as the sticks are turned in opposite directions by four people, any substance in the bag is squeezed so that the liquid part runs out. *See also* 1500 BCE FOOD

❖ Materials

“Egyptian faience” is found in the lower Nile valley for the first time. Probably it was imported at this time from Mesopotamia, although Egypt eventually was to develop a thriving faience industry of its own. *See also* 4500 BCE MATR; 2000 BCE MATR.

The rich deposits of copper ore on Cyprus are discovered and from this date forward become the main source of copper for the ancient world. *See also* 3500 BCE MATR; 2500 BCE MATR.

Metallurgists in the Near East (Syria or eastern Turkey) discover shortly before this time that addition of tin ore to copper ore before smelting produces bronze, a harder and more useful metal than cop-

per that is also easier to cast. The new metal’s utility is such that the whole subsequent era is known as the Bronze Age. *See also* 3700 BCE MATR; 2500 BCE MATR.

In Mesopotamia, bitumen (asphalt) is used as an adhesive, to hold bricks together. *See also* 2400 BCE MATR.

Sumerians use pins made from bone to hold clothes together. *See also* 13,000 BCE MATR; 2200 BCE MATR.

Σ Mathematics

An early form of abacus consisting of beads strung on wires is used in the Orient. *See also* 1000 BCE MATH.

♥ Medicine & health

Tooth filling occurs in Sumeria. *See also* 1000 BCE MED.

The Iceman Ötzi

One spring day about 5300 BP a man near what is now the border between Italy and Austria was shot with a flint arrow. He fled into the mountains, removing the arrow shaft, but the arrowhead remained embedded in his shoulder bone. It is thought that he collapsed and died from loss of blood. Somehow his body remained undisturbed until fall, when it was covered with snow and ice. The climate cooled and the snow and ice became year-round. In a later warm spell, the body was exposed, but then cold weather returned. The ice cover became a glacier, but with global warming, that glacier is now melting. In September of 1991, two hikers found the mummified body exposed. The remains were taken first to Austria, then to Italy, where the man gained a new name — Iceman or Ötzi (he was found in the Ötztal mountains).

The story of Ötzi’s last days is a best guess reconstruction. It was spring because his intestines contained pollen from spring flowers. The arrowhead was spotted during a CT scan of his body. Other damage, earlier thought to have caused his death, resulted from the action of ice on the body.

The remains reveal much about tools and material used in Europe at that time. Leather sewn together with sinews was used

for clothing, although a large cloak was woven grass. A cap was made from the fur of a brown bear. The shoes had soles of bear leather and uppers of deerskin; they were stuffed with grass and hay for insulation. Woven grass was also used in place of sinews. His dagger was of flint inserted into a wooden handle and secured with string; it was placed into a woven-grass sheath that had a leather loop to attach the sheath to his belt. Another piece of flint may have been employed as a drill. A bone tool was similar to an awl. His arrowheads were also flint. The axe is the oldest complete one known. The flanged axe head was of copper and was attached to the wooden handle by strips of leather and birch pitch. A birch-bark box contained charcoal wrapped in maple leaves (possibly a method of carrying smoldering coals to start a fire, since no fire-starting flint was found). Two lumps of birch fungus are thought to have been carried as a first-aid kit for use as medicine.

In his leather and hazelwood quiver there were two finished arrows, dressed with feathers to cause spin, and 12 unfinished arrows, all made from viburnum and dogwood. One of the finished arrows is a type called a composite that has a short shaft attached to a longer one, designed so the longer part can be broken off by a wounded animal while the short part will remain. The arrowhead embedded in Ötzi’s shoulder is an exact match for the type found in his quiver.

Mesopotamian mathematics

Because baked clay tablets with cuneiform symbols impressed are easily preserved, especially in a dry climate, much is known about Mesopotamian mathematics. Some historians think that it is likely that a great deal of the mathematical knowledge of the ancient world, ranging from Rome to China, diffused from Mesopotamia. The Mesopotamian numeration system was based on 60 as well as 10, and scholars can trace this division through many different languages. The most notable reflections of this system today are in the divisions of hours, minutes, and seconds in time calculations and in the divisions of degrees, minutes, and seconds for angle measurements. The break at 10 in Mesopotamian notation was purely additive (that is, three tens is shown by repeating the tens symbol three times), as in many simple and inconvenient numeration systems, such as the Egyptian and Greek; but the break at 60 represented true place value, making the Mesopotamians one of the four cultures that developed place value (along with the Chinese, Indian, and Maya). Some evidence suggests, however, that the Chinese and Indian place-value systems were influenced by diffusion from the Mesopotamian system, although it is also possible that the Indian system developed from diffusion from China. In any case, the Mesopotamians lacked one essential for a modern place-value system: They did not have zero. A symbol for zero was probably invented either in Indochina or India about the seventh century ce. Zero was also invented independently by the Maya, probably a hundred or so years earlier than the Indian invention, but it did not have a chance to spread around the world.

Even without zero, the Mesopotamian place-value system provided many benefits, including simple algorithms for the basic

arithmetic operations. Furthermore, the Mesopotamians made the logical step of extending the places to numbers smaller than one, just as we do with decimals. Sexagesimal fractions are just as convenient as decimal fractions. They contributed to Mesopotamia's developing a practical method for finding square roots, essentially the same method once taught in elementary and secondary schools in the United States, but now replaced with the use of electronic calculators.

Mesopotamian mathematicians were the most skilled algebraists of the ancient world. They were able to solve any quadratic equation and many cubic equations. It is possible that their methods diffused to India and from there back to the Arab world, from which algebra reached the West.

It was once fashionable to say that the Mesopotamians were good in algebra but weak in geometry. Later discoveries have forced a revision of this belief, since it is clear that the Mesopotamians were the earliest people to know the Pythagorean theorem (Pythagoras, who is known to have traveled in the East, may have learned his famous theorem there). The Mesopotamians also possessed all the theorems of plane geometry that the Greeks ascribed to Thales, including the theorem of Thales: An angle inscribed in a semicircle is a right angle. It seems unlikely, however, that these mathematicians proved their theorems from first principles, as Thales is said to have done.

Probably the criticism of Mesopotamian geometry began because some writings seemed to use a value of three for π , a value that made its way into the Bible (indirectly — a circular bowl is described as having a circumference three times its diameter). Later discoveries, however, have shown that at least some Mesopotamians used 3.125 for π , about as good a value as their contemporaries in Egypt had.

I Tools

Axes in Mesopotamia are made with bronze or copper heads that have a hole in them where a shaft can be inserted.

People in early civilizations begin to grind lenses of rock crystal, a practice continued by the Greeks and Romans. *See also* 300 BCE TOOL.

→ Transportation

Ruins from this period in Mesopotamia sometimes include seashells and minerals from India and Ceylon, suggesting that trade by boat may have taken place between the people of Mesopotamia and the people of Harappa and

Mohenjo-Daro (Pakistan). *See also* 4500 BCE TRAN; 2600 BCE TRAN.

Egyptian boats are essentially papyrus rafts, although shaped with upturned ends (that is, not rectangular, like log rafts). Both Egyptian and Mesopotamian boats are propelled by either humans using paddles or the wind pushing a simple single square sail. Rowing has not been discovered. *See also* 3500 BCE TRAN; 2500 BCE TRAN.

Wheels used with vehicles are strengthened by nailing a wooden rim around the outside. *See also* 3500 BCE TRAN; 2000 BCE TRAN.

2900 BCE

↳ Communication

Egyptian scribes devise a form of writing now called hieratic script, a simplified form of hieroglyphic writing with symbols joined together, as in the cursive writing used in modern languages that employ the Roman alphabet. *See also* 3300 BCE COMM.

2800 BCE

▲ Archaeology

Mycenaean invaders from the plains of the Black Sea and from Asia Minor begin an

800-year-long conquest of the native peoples occupying Greece. *See also* 1200 BCE ARCH.

Kings, called lugals ("big men"), replace councils of elders in the government of the city-states of Sumer. *See also* 3500 BCE ARCH; 2700 BCE ARCH.

★ Astronomy

Astronomical evidence shows that by 2782 BCE the Egyptians have instituted a 365-day calendar, although the evidence can also indicate that the calendar was introduced as early as 4242 BCE. *See also* 3114 BCE AST.

Early sailing

Even before the oar was invented, people had learned of a better way to propel boats for most purposes. Anyone who has ever tried to paddle a canoe in a stiff breeze can recognize the power of wind to move boats through water, often not in the direction one wants to travel. The earliest drawing showing a sail dates from about 3200 BCE, although known trade patterns suggest that sails had been in existence for at least 300 years when this drawing was made.

The arrangement of sails has been slowly improved. Any flat, stiff object can be used as a sail to propel a canoe or small boat in the direction the wind is blowing. It takes adjustable fabric sails, more than one, to move a large ship into the wind. The first flat sails were soon replaced by bags for the wind. A bag-of-wind sail is a loose sail held at its corners, in contrast to the tight, nearly flat sails most commonly used today.

The single bag-of-wind sail persisted for about 3000 years before a second one was added. This soon led to ships with three masts and the beginning of masts that carried more than one

sail. By the time of the early Roman Empire, sailing ships existed with sails rigged more like those of a modern small pleasure boat, with large, fairly flat triangular sails jutting away from the mast instead of square or triangular bags of wind centered on the mast. For the next thousand years, the ships of the Mediterranean followed the main sail designs that had been worked out earlier. The triangular lateen sail and variations on it became especially popular. These Mediterranean ships were first steered by a paddle from the side, reflecting the heritage of the canoe. Later a pair of side-mounted steering paddles were used.

During Roman times and afterward, effective ships that sailed the North Atlantic evolved separately from those in the Mediterranean. Northern ships developed their own rigging and construction methods. A principal innovation of the northern school was the replacement of a steering paddle or side rudders used in the Mediterranean by a true stern rudder (although there is good reason to believe that the stern rudder idea was lifted from the Chinese). During medieval times, the traditions of the Mediterranean and Atlantic were combined into the ancestors of the efficient sailing ships of the Renaissance and later days.

■ Construction

Corbeled arches and domes are common in Mesopotamia. Corbeling refers to building an arch or dome with layers of brick or stone set up so that each layer projects beyond the one beneath it, like an upside-down staircase. Contrary to popular belief, the true arch was also invented around this time, although its greatest use was thousands of years away during the Roman Empire. *See also* 3500 BCE CONS; 1900 BCE CONS.

■ Food & agriculture

The sweet potato is grown along the west coast of South America (Peru). *See also* 3100 BCE FOOD; 2400 BCE FOOD.

2750 BCE

★ Astronomy

Stone structures in Europe and in Egypt are aligned so that the Sun or a particular star shines through a chosen opening at special times of the

year, such as at the summer solstice. *See also* 3500 BCE AST; 1500 BCE AST.

■ Construction

The first version of Stonehenge is constructed on the Salisbury Plain (England). It consists of an earthen bank and a ditch, along with 56 pits known as the Aubrey Holes, after John Aubrey [b. Kingston, Wiltshire, England, March 12, 1626, d. 1697], who discovered them, and only three stones, including the Heel Stone. *See also* 2200 BCE CONS.

2700 BCE

■ Archaeology

The city of Uruk (Iraq), ruling over 76 outlying villages, is based in an urban area that extends over 400 hectares (1000 acres), surrounded by a 10 km (6 mi) wall. Its population has grown to nearly 50,000. *See also* 2800 BCE ARCH; 2335 BCE ARCH.

■ Communication

Contracts are being used in Sumer.

■ Food & agriculture

Culture of silkworms is started in China. According to legend, Se Ling-she the wife of Emperor Huang-ti, is the first to unroll a cocoon and make silk. *See also* 53 BCE MATR.

■ Medicine & health

Acupuncture is practiced in China.

→ Transportation

Bowls found in Minoan ruins on Crete that date from this time appear to have been made in Egypt, suggesting seagoing trade between the two. It is thought that the Minoan ships traded all over the Mediterranean by this period. *See also* 3000 BCE TRAN; 2600 BCE TRAN.

2630 BCE

■ Construction

Pharaoh Djoser commissions architect Imhotep to build a stone tomb for his body after his death. The result is the first step pyramid, 62 m (204 ft) high with a base that measures 126 m (413 ft) by 105 m (344 ft). *See also* 7500 BCE CONS; 2590 BCE CONS.

2600 BCE

■ Archaeology

The Sphinx is carved from limestone bedrock in Egypt. *See also* 1401 BCE ARCH.

■ Medicine & health

Egyptian embalmers take the first steps toward mummification of bodies by beginning the practice of removing the internal organs of dead pharaohs. These organs are preserved in jars in a salt solution, while resin-soaked linens replace them in the body. *See also* 3000 BCE MED; 2500 BCE MED.



Imhotep

[b. near Memphis, Egypt, flourished 2650–2590 BCE]

Imhotep is supposed to have designed the step pyramid built for Pharaoh Djoser, the first tomb in the shape of a pyramid, but he is also remembered as a great physician. According to some accounts he advised the pharaoh on how to appease the gods after a seven-year famine caused by failure of the Nile flood, a story similar to parts of Joseph's life as recounted in the Hebrew Bible. Imhotep is the first named person who might be considered a scientist in history.

Transportation

A command from the Egyptian pharaoh Seneferu (reigned c. 2614 BCE to 2591 BCE) to bring “40 ships filled with cedar logs” to Egypt from Lebanon is the first written record of the existence of boats and shipping. *See also* 2700 BCE TRAN; 2500 BCE TRAN.

Wheeled vehicles are in use in China; the Xue clan becomes especially identified with carriage building. *See also* 3000 BCE TRAN.

2590 BCE

Construction

Pharaoh Snefru orders the eight steps of the step pyramid that is to be his tomb filled in, resulting in the first true pyramid tomb in Egypt. *See also* 2600 BCE CONS; 2575 BCE CONS.



GREAT PYRAMID The large pyramid tombs of ancient Egypt are still awe-inspiring today. The largest are more massive even than most modern buildings.

2575 BCE

Construction

The Great Pyramid of Giza is started as a tomb for Egyptian Pharaoh Khufu (known in Greek as Cheops). The base is

an almost perfect square, with the greatest deviation from a right angle only 0.05 percent. The orientation of its sides is exactly north-south and east-west. Completion takes about a quarter century. *See also* 2590 BCE CONS; 1600 BCE CONS.

The calendar

The first quantity that people could measure with any degree of accuracy, and on which all people could agree, was time, although only fairly large amounts of time. Large amounts of time can be easily measured because the universe itself supplies “clockwork” in the daily and annual motion of Earth and the moon. Even so, the measurement of time was not easy to work out. A day is one revolution of Earth; a Moon is from one new Moon to the next; but it is not so easy to measure a year. Even the day is not as easy to measure as it seems. It took a while to learn to measure the day from one noon to the next (noon is when the Sun reaches its highest point in the sky).

The ancient Egyptians were the first to establish a good length for the year, possibly because the Nile floods around the same time each year. This flooding generally coincides with the heliacal rising of Sirius: that is, when Sirius rises at about the same time as the Sun. Although there are 365 days between such risings, the year is actually 365 days, 5 hours, 48 minutes, and 46 seconds, or about a quarter of a day longer than 365 days. Since the year is not exactly 365 days, the Egyptian calendar gradually

went into and out of alignment with the seasons with a period of about 1460 years.

No one knows for sure when the Egyptians began using a 365-day calendar. The Egyptian calendar accurately matched the seasons with dates in 139 CE, since according to Roman historian Censorinus, the heliacal rising occurred on the Egyptian New Year in that year. Knowing this one date, astronomers have speculated that the year of 365 days was instituted in Egypt around 1322 BCE, 2782 BCE, or even 4242 BCE, going backward in leaps of 1460 years.

Hellenic astronomers added the missing quarter day to the Egyptian calendar by adding an extra (leap) day every four years, but most people ignored it. The calendar with a leap day was finally adopted by the Romans under Julius Caesar in 46 BCE with the first leap year added in 45 BCE. But errors in applying the rule in the following years (priests thought Caesar meant a leap year every third year!) resulted in restarting the system in 8 CE, with leap years every four years thereafter. Since then, the calendar has had one major modification, when Pope Gregory, in 1582 CE, on the advice of astronomers, dropped the leap day in years that end in two zeros unless the year is also divisible by 400 (for example, 2000 was a leap year but 2100 will not be).

How did the Egyptians build the pyramids?

The Great Pyramid of Khufu was one of the Seven Wonders of the World to the ancients and we still marvel at it today. Although it is not the largest pyramid of the past — honors go to an otherwise undistinguished pyramid from Cholula, Mexico, that was built about half as far back — Khufu's pyramid amazes because of its antiquity, the size of its stones, the perfection of its orientation, and its many hidden chambers. Outwardly about as simple as an edifice can be, the Great Pyramid is actually a complex and interesting object. Furthermore, it is flanked by two nearby pyramids, each almost as large, that would be wonders by themselves if the Great Pyramid had never been built.

The Greek historian Herodotus, writing about two millennia after construction of the pyramids, claimed that it took teams of 100,000 men at a time working for 20 years to build them.

Herodotus also claimed that the ancient Egyptians had marvelous machines that they used to lift the stones into place. Neither of these claims seems to be true.

A current misconception is that the Egyptians moved the large stones on rollers made from tree trunks. According to this theory, by having teams constantly replenish the front rollers with those from the rear, it should have been possible to move a stone almost as if the wheel had been invented. This is idle speculation with no evidence in its favor and much circumstantial evidence against it.

The most reliable clues to Egyptian construction methods are the wall paintings from ancient Egypt, although many of the most suggestive are far from contemporaneous with the pyramids. Using such paintings and some related texts, along with practices employed in more recent times and a few artifacts, we can put together the following scenario:

- **Quarrying.** Decent limestone beds on the same side of the river as the pyramids and good limestone from the far side were used. Limestone was cut in blocks by making notches with hard rock, inserting wooden wedges, and wetting the wedges. When the wedges swelled, the stone fractured. Sometimes copper wedges in increasing sizes were used instead. Granite, used for plugs and caps, may have been cut by pounding it with a harder stone.
- **Transporting.** Very heavy objects, some ten times the weight of pyramid stones, are shown in wall paintings as being moved on sledges, not on rollers or wheels, considerably later than when the pyramids were built. Wheels were new in Mesopotamia around the time of the pyramids, but word had not reached Egypt. The sledges were aided by pouring a liquid in their path to lubricate the way. Some have speculated that the liquid was milk, but vegetable oil of some kind seems within the abilities of Egyptians of the time (and much more efficient).
- **Leveling.** Anyone who has tried to make a large region level knows that it is far from easy, but the base of the Great Pyramid

is much more level than the foundations of many modern buildings. Farmers today use lasers to level fields, but ancient Egyptians probably used shallow ponds. A brick or mud wall can be used to enclose the site. Introduce water to make a pond; its surface will be level. Then drill holes to a fixed depth below the surface. Remove the water; the bases of the holes mark the level surface; just remove everything down to this base.

- **Orienting.** Although most people think of lifting or transporting the stones as the most difficult part of building a pyramid in ancient times, orienting it so that one side of the base is perfectly north-south is much more difficult. For one thing, there was no pole star 5000 years ago; Earth's axis moves in a circle once every 26,000 years. At sea, it is possible to use the rising and setting of any bright star to find north; the bisector of the angle between such a rising and setting will be either due north or due south. But that method relies on the nearly level circular horizon provided by the sea, which is not available where the pyramids were built. But since the Egyptians knew how to make a level surface, they could build a semicircular wall with a level top and use that as an artificial horizon.
- **Squaring.** Perhaps even more difficult than finding north or south is finding true east and west. Egyptian masons commonly worked with the tool that we call a square, and square corners are common in Egyptian buildings. But the squareness of the Great Pyramid is so good that something more accurate must have been employed. It is known that more than a thousand years later Egyptian surveyors used a rope knotted to make a right 3-4-5 triangle. If the sides are measured accurately, such a triangle will give a perfect right angle. Also later Egyptians probably knew that an angle inscribed in a semicircle is always a right angle.
- **Slanting.** Keeping the slope of the sides the same over an area of 31,000 sq m (7.7 acres) was another difficult task. It seems likely that the masons used the diagonals of the square to locate its center and erected a vertical pole (using their ability to find right angles) to the planned height of the finished pyramid. They could then sight to find the correct slope. An error in this procedure might have accounted for the Bent Pyramid of Seneferu (c. 2650 BCE) at Dajshur, although the change in slope halfway up from about 54° to about 43° is usually ascribed to running low on money before the pyramid was complete.
- **Lifting.** This is the easy part. Instead of lifting the stones, some as heavy as 150 tons (although the average limestone block was only about 2.5 tons), the Egyptians built long ramps to the working level so that stones could be moved up on sledges. Then levers and wedges were used to put the stones in place.
- **Lowering.** The outer blocks were cut in final form and lowered very carefully so that the process would not damage the facing. It is thought that this was accomplished by lowering from one set of wooden braces to another, with each set of braces only about a centimeter (half an inch) lower than the one above it.

2550 BCE**■ Construction**

A large circle of standing stones is built at Avebury (England), some as much as 14 m (46 ft) high. The entire site, including earthworks and ditches, encompasses 11.5 hectares (28.5 acres).

→ Transportation

The Lapita culture, which originated in the Bismarck archipelago near New Guinea perhaps as early as 7000 BCE, reaches New Caledonia island, where the community for which the culture is named is started. It is characterized by the use of large oceangoing double-hulled canoes that enable the Lapita people to spread throughout the South Pacific.

2500 BCE**■ Archaeology**

The Longshan people of the Huang He (Yellow River) become the first civilization of China, living in larger communities, using the potter's wheel, and breaking into social classes. *See also* 700 BCE TOOL.

■ Construction

People we know as Harappans begin to construct cities on the banks of the Indus River and its tributaries (Pakistan). At Harappa itself they build a huge citadel nearly 425 m (1400 ft) long and 180 m (600 ft) wide along the floodplain of the Ravi, a major tributary of the Indus, apparently not only to defend against rising waters but also against invading people. *See also* 2350 BCE TRAN.

Civilizations in Crete, in the Cyclades (islands in the Aegean Sea), and in parts of Greece build tile-roofed houses that contain several rooms. *See also* 6000 BCE CONS; 2100 BCE CONS.

A dam about 84 m (276 ft) long, 110 m (361 ft) wide, and 12 m (39 ft) high is built at Wadi Gerrawe (El Kofaro) sometime before this date. Lined with limestone blocks, the dam's apparent purpose is to catch the water from the occasional flooding of the Wadi that occurs during the winter rains. It is not designed well enough, however, and the first large flood collapses it. *See also* 3000 BCE CONS; 1300 BCE CONS.

■ Food & agriculture

Yams are cultivated in western Africa.

The yak is domesticated (Tibet). *See also* 3000 BCE FOOD; 1000 BCE FOOD.

Ducks are domesticated in the Near East. *See also* 7000 BCE FOOD.

The cat is kept in people's houses and on farms in Egypt. It is never completely domesticated. One of the six major cities of Lower Egypt, Bubastis, is dedicated to the cat goddess. *See also* 18,000 BCE FOOD.

♦ Materials

Chinese epics mention copper, although it is not clear how well developed the practices of copper mining or smelting are at this time. *See also* 3000 BCE MATR; 100 BCE MATR.

Animal skin used for writing seems to have been employed by about this time, but the

practice is sporadic and the material is not treated as much as later forms of parchment, which is also made from treated animal skins.

Tin is mined and smelted by a low-temperature, complex process at what is now Goltepe, Turkey. This is the earliest known source of the tin used to make bronze for the Bronze Age. *See also* 3000 BCE MATR; 2000 BCE MATR.

Metal mirrors are used in Egypt. Metal axes replace stone in Mesopotamia.

A form of soldering to join sheets of gold is used by the Chaldeans in Ur (Iraq). *See also* 700 BCE MATR.

Σ Mathematics

Standard weights, used in trade, are developed by the Sumerians. They are based on the shekel of 8.36 g (129 grains) and the mina, 60 times as heavy. *See also* 2400 BCE MATH.

♥ Medicine & health

Egyptian carvings show a surgical operation in progress. *See also* 1550 BCE MED.

I Tools

Many tools used by masons are in existence, including plumb lines to find the vertical, levels to find the horizontal, squares to find right angles, and mallets. *See also* 3000 BCE CONS.

In Egypt the tools of war include wheeled ladders used for scaling walls during a siege. *See also* 2000 BCE TOOL.

→ Transportation

Clay tablets record imports to southern Mesopotamia of stone from either Magan or

Makran (both on the Persian Gulf). Magan developed a reputation as a port, and the stone was probably transported by boat to the mouth of the Euphrates at the head of the Gulf and then up the Tigris-Euphrates river system. *See also* 2600 BCE TRAN.

Boats in Egypt are made of wood instead of being papyrus rafts with upturned ends. Oars have probably been invented. *See also* 3000 BCE TRAN; 2450 BCE TRAN.

Wheeled vehicles, basically chariots, are used by Sumerian armies. *See also* 3500 BCE TRAN.

2490 BCE**■ Construction**

Less than a hundred years after the building of the Great Pyramid of Khufu, when the largest stones moved were granite slabs weighing about 50 tons, workers are able to move stones weighing as much as 220 tons to build the mortuary temple of Pharaoh Menkaure (Mycerinus in Greek histories). *See also* 2575 BCE CONS; 1285 BCE CONS.

2450 BCE**→ Transportation**

Egyptian Pharaoh Sahure orders for his pyramid a representation of the fleet he had built to ferry troops to the Levant coast. This is the earliest known depiction of seagoing ships that has been preserved and the earliest recorded use of ships for military purposes. Ships were undoubtedly used in war earlier even though we have no

Paddles and oars

Humans have a close affinity with water. Swimming is considered recreation, for example. Humans also relish shellfish (even raw) and other ocean creatures. Transportation over water by means of rafts appears to go back to earliest times, possibly even to such ancestors as *Homo erectus*. Early rafts would have been propelled through waters too deep for poling by the first forms of paddle.

Unwieldy rafts were eventually replaced by canoes, almost certainly the first form of boat. Although still paddled, the canoe is shaped to make for easier steering and passage through water than a raft. The earliest known canoes are from nearly 10,000 BP, although similar craft probably were built much before. The small canoe is still a useful boat. But, although Polynesians and South American Indians eventually built giant war and cargo canoes, larger paddled vessels have been replaced by ships with more powerful means of propulsion.

An oar is just a paddle in which the fulcrum that is one hand for the paddle is replaced with a fulcrum (the oarlock) attached to the hull of the boat. As a result, only one arm is needed to use an oar, so one person can operate oars on both sides of a boat at once. Thus, rowing takes a lot less skill than paddling, which

needs two hands and is done on one side at a time. Furthermore, as the size of a boat is increased, separate rowers can be assigned to several sets of oars on each side. Also, the mechanical advantage of the lever can be increased by lengthening the oar more effectively than by using a longer paddle. Two or more persons can pull a single long oar.

The ability to use several sets of oars was most important during war. Although sails were invented earlier than oars, designers of warships preferred rowing to sailing in battle. Sails are wonderful for transporting large amounts of goods with small crews, especially in regions where winds can be counted on. For fast maneuvering with no dependence on the vagaries of winds, however, ancient military planners turned to ships powered (during battle at least) by oars.

From about 1000 BCE until about 200 BCE shipbuilders gradually increased the number of oars and the number of rowers per oar in an effort to produce ships that were faster and more powerful than those of their enemies. This trend culminated in a ship that used 4000 rowers, but that was too unwieldy to take into battle. Rowing with variations in methods of attack continued to be an important part of naval practice until the invention of the cannon in the 14th century completely revolutionized war at sea.

record of it. *See also* 2500 BCE TRAN; 1450 BCE TRAN.

2400 BCE

Food & agriculture

Manioc (cassava, also prepared as tapioca) is grown in South America along the west coast (Peru), although it probably was domesticated earlier in the tropical inland region. *See also* 2800 BCE FOOD; 2000 BCE FOOD.

The honey bee is domesticated in Egypt earlier than this date, for a temple drawing from this time shows the earliest known depiction of bee-keeping and honey preparation. *See also* 2700 BCE FOOD.

The domesticated two-humped Bactrian camel is present (Turkmenistan or Iran), although probably domesticated earlier (Kazakhstan, northern Mongolia, or northern China).

People living on the west coast of South America (Peru) begin to divert river water into their fields. *See also* 6000 BCE FOOD; 2000 BCE FOOD.

Materials

Records indicate that bitumen, derived from petroleum seepage, is used in great quantities for waterproofing by the inhabitants of Mesopotamia, with shipments to Ur of over a hundred tons from sites such as Hit on the Euphrates or other centers. Bitumen mixed with sand or fiber (called mastic) is also used as a building material during this period and until Antiquity. *See also* 3000 BCE MATR.

Mathematics

The oldest preserved weight, found in the Mesopotamian city of Lagash, is 477 g (about 17 oz). *See also* 2500 BCE MATH; 2100 BCE MATH.

2350 BCE

Transportation

Regular trade begins between the Harappan civilization on the Indus River (Pakistan) and Sumer and Akkad in Mesopotamia (Iraq). *See also* 2500 BCE TRAN; 2300 cons.

2335 BCE

Archaeology

Sargon the Great, an Akkadian (a Semitic people from the Arabian Peninsula who settled north of Sumer about 3000 BCE), begins his 56-year rule. He conquers all of Sumer, uniting it under one ruler for the first time. *See also* 2700 BCE ARCH; 1900 BCE ARCH.

2300 BCE

Communication

A map of the city of Lagash in

Mesopotamia is carved in stone in the lap of a statue of a god; it is the oldest surviving map of a city. According to legend, Sargon of Akkad also produces maps in Mesopotamia for land taxation purposes. *See also* 6200 BCE COMM; 1500 BCE COMM.

Construction

At its height, the Indus River (Pakistan) civilization we call Harappan is led by two nearly identical cities laid out with straight streets on north-south grids — Harappa on an inland tributary of the Indus and Mohenjo-Daro, 560 km (350 mi) to the south, on the lower Indus. Both cities have public buildings of fired brick, while personal dwellings or landfill are of sun-dried brick, uniformly made in each city. Houses are constructed around interior courtyards with the rooms plastered inside with mud or gypsum.

Most houses feature indoor toilets and places where people can wash themselves with water carried in pitchers, often from wells inside the house. All bath facilities flow into a municipal sewage system that runs beneath major streets. Solid waste is collected in bins in the streets connected by trash chutes to the interior of houses. *See also* 2350 BCE TRAN; 1750 BCE ARCH.

🍴 Food & agriculture

A clay figurine of a domestic horse from Tell Es-Sweyhat about 320 km (200 mi) north of Damascus, Syria, is the best early horse sculpture known and confirms domestication (other evidence suggests that the horse was originally domesticated much earlier). Thomas Holland, who directed the expedition that found the horse in 1992, believes that

the principal use of the horse in the Middle East at this time was in the breeding of mules, favored for pulling chariots (although horses also pulled chariots at the time as well). *See also* 3500 BCE TRAN; 300 BCE TRAN.

❖ Materials

People in Central America make pottery. *See also* 7000 BCE MATR.

2296 BCE

★ Astronomy

Chinese observers record a comet, the earliest known record of a sighting. *See also* 5 CE AST.

2200 BCE

🏗 Construction

Eighty bluestones are set up at

Stonehenge (England) in the form of two concentric circles. *See also* 2750 BCE CONS; 1450 BCE CONS.

According to legend, Queen Semiramis builds the first tunnel below a river (the Euphrates), linking the royal palace in Babylon with the Temple of Jupiter — but present-day engineers think that her workers did not have the technology to accomplish this. *See also* 700 BCE CONS.

2136 BCE

★ Astronomy

The Chinese record of a solar eclipse is the first report known of such an event. The partial eclipse is mentioned because two astronomers were put to death for failing to observe the proper rites during the event. *See also* 3000 BCE AST; 450 BCE AST.

2100 BCE

🏗 Construction

Ur-Nammu disposes of rivals and rules from the city of Ur (Iraq), becoming the last great ruler of Sumer. He is known for rebuilding the cities and canals, as well as constructing a ziggurat (temple tower) that rises 21 m (70 ft) with a base 60 m (200 ft) wide. *See also* 2335 BCE ARCH.



STONEHENGE The most famous megalith of Europe, Stonehenge was almost certainly intended to be used for astronomical sightings, such as locating the summer solstice.

Early units of measure

The ancients developed moderately accurate ways to measure several quantities: time, length, area, volume, weight (or mass), capacity, and angles. They had no way to measure some other quantities, such as temperature, force, and pressure, which until the 17th century could only be roughly estimated by human senses.

The most ancient peoples used time to measure some large quantities, such as length or area. A journey was so many hours, days, or — for a very long journey — moons. An acre was the amount of land that a person driving a yoke of oxen could plow in a day, and the length of the furrow was the furlong. But small amounts of time could not be measured very accurately, so other means for smaller measures were employed.

Many ancient measures of length came from body parts, similar to the foot and other familiar U.S. customary units. The yard was the distance from the tip of the nose to the end of the fingers when the right arm was outstretched. The inch was probably once the last joint in the thumb, since the word *inch* seems to come from *uncial*, Latin for thumb.

A problem with measures based on body parts is that human bodies differ in size. One attempt to solve this was to use the king's body to represent the normal size, so that the official yard

was based on the king's nose and arm. The earliest preserved standard measure for length is the foot of a statue of Gudea, the governor of Lagash, a Mesopotamian city-state of about 2000 BP.

For a system of measures, it is important to have clear numerical relationships. If the king's foot is standard, then defining the inch so that there are 12 inches exactly in a foot is better than using the king's thumb.

The Egyptian way was to start with the smallest unit and build up. Four digits (a measure similar to the inch) made a palm, and seven palms made a cubit. From measuring Egyptian structures, modern archaeologists have determined that the Egyptian cubit was standardized at 52.37 centimeters (20.62 inches).

Standards could be lost over time. One of the first set of standard measures was enacted by the English Parliament in 1215, based on physical representations. But when the houses of Parliament burned on October 16, 1834, the standard yard and standard pound burned with them. In the British colonies that became the United States, the same measures as had been used in Britain were kept, but their actual sizes began to vary from those used in England and even from American state to state. In 1832 the U.S. Congress decreed that the different weights and measures in use at the several custom houses should be averaged. That average became the first version of the U.S. customary system.

The megaron house that becomes the model for much of the housing around the Mediterranean is developed, as revealed by excavations at the lowest level of Troy (Hissarlik, Turkey). A columned porch leads into a narrow hall that passes into the large main room (*megaron*). Later developments in Greece include another small room behind the megaron for sleeping or storage and a circular hearth. *See also* 2500 BCE CONS.

Mathematics

The oldest preserved standard for length is the foot of the statue of the ruler Gudea of Lagash. It is divided in 16 parts and is 26.45 cm (10.41 in.) long. *See also* 2400 BCE MATH.

Medicine & health

The oldest medical text that has been preserved in its original form is a cuneiform tablet

that lists a sequence of recipes for various external poultices and plasters. *See also* 2000 BCE MED.

2000 BCE

Archaeology

The Aryans from the Eurasian steppes and the Iranian plateau region cross the Hindu Kush mountains and settle in what is now northern India and Pakistan.

Biology

The first zoo in China, called the Park of Intelligence, is founded.

Communication

A postal system for royal and administrative messages exists in Egypt. Messages are relayed from one messenger to another.

Construction

The Cretan palace of Minos contains sewage systems and interior bathrooms with a water supply. *See also* 2300 BCE CONS.

Ecology & the environment

Pygmy mammoths living on Wrangell Island off the north coast of Siberia (Russia) become extinct. *See also* 9000 BCE FOOD.

Food & agriculture

Domestic cats are kept by the Lake Dwellers of Switzerland. It is probable that various species of wild cats were domesticated separately in different parts of the world. *See also* 3000 BCE FOOD.

In both Egypt and Mesopotamia the shaduf is introduced for watering fields. Essentially, a shaduf is a long pole on a pivot with a bucket suspended

from one end of the pole and a counterweight at the other end, making lifting a heavy bucket of water from a river or a canal a fairly easy task. The shaduf is still used today in Egypt and in Asia. *See also* 2400 BCE FOOD.

The first seed drills are made by adding a funnel that directs seed into a hole in a wooden plow. Seeds poured into the funnel are deposited right into the plowed furrow. *See also* 3000 BCE FOOD; 1500 BCE FOOD.

Paddy culture of rice occurs in southeastern Asia. *See also* 4000 BCE FOOD.

Alfalfa is cultivated (Iran).

Materials

Sandals, probably in use long before this, are buried in an Egyptian tomb; they are made from braided papyrus. *See also* 3300 BCE COMM.

Metalworkers on the Khorat Plateau (northeast Thailand) become experts in casting tools and ornaments of bronze, aided by a plentiful supply of tin ore in close proximity to copper ore (this development may have started as much as 500 years earlier). *See also* 2500 BCE MATR.

Sometime before this date a manufacturer of “Egyptian” faience overheats his core of quartz sand and sodium carbonate (naturally occurring as natron), melting the whole mass. This is the first production of glass by humans. Glassmakers soon find that lime — usually found in natron or in the sand they

used — is needed for glass and that lead makes it brighter, but it is a long time before they realize that glass can be molded while hot. Instead, early glassmakers allow it to cool and then work it as they would obsidian (naturally occurring volcanic glass), cutting and polishing the glass to make useful or attractive objects. *See also* 3000 BCE MATR; 1600 BCE MATR.

Two Mesopotamian women, Tapputi-Belatekallim and (...) ninu (first part of name is lost) develop perfumes; (...) -ninu writes a text on perfumery.

Σ Mathematics

By this date Mesopotamians learn to solve quadratic equations; that is, equations in which the highest power is 2. *See also* 1850 BCE MATH.

The system of measures used in Mesopotamia includes, besides the shekel and mina, units of capacity — the log (541 ml or 33 cu in.) and the homer, equal to 720 logs — as well as length: the cubit and the foot, which is two-thirds of a cubit. *See also* 2100 BCE MATH; 1950 BCE MATH.

♥ Medicine & health

Physicians form an important professional group in

Mesopotamia. Their medical practice is strongly based on astrology and belief in demons. *See also* 2100 BCE MED.

Contraceptives are in use in Egypt — an illustration shows a man wearing a condom. Herbal preparations to prevent conception or to induce abortion are even older. *See also* 2500 BCE MED.

I Tools

In Egypt people use a drill turned by a bow (the string is wrapped around the drill and the bow is moved back and forth) to drill holes in stone. *See also* 3500 BCE TOOL.

Egyptian medicine

Sometime before 2000 BCE, Egyptian priests began to develop the world's first sophisticated medical practice. Although it is believed that all early cultures learned some forms of herbal cures and methods of surgery, the Egyptian priests were the first to codify their knowledge in a way that scholars can interpret today. The fame of the Egyptian healers was so great that the rich and noble from all around the Middle East and, later, the whole Mediterranean basin traveled to Egypt to be treated.

One semilegendary figure, Imhotep, who flourished sometime around 2600 BCE, is often considered to be the first scientist known by name, although he was not a scientist in the modern sense of the word. Famous as a physician, he is also credited with being the architect of the step pyramid for the pharaoh Djoser. After his death, Imhotep was assigned a godly ancestry and magical powers. Imhotep has been called the only scientist ever to have become a god.

It is widely assumed that Egyptian priests gained their understanding of the human body by preparing mummies. Priests removed for special treatment the internal organs of a cadaver being mummified. Although dissection presumably was the basis of their knowledge, the evidence is that most treatments for disease were based on trial-and-error experimentation. Moldy bread was put on wounds, an application of the mold that produces penicillin. Castor oil as a purgative and poppy juices to

relieve pain were also commonly used. Radishes, garlic, and onions were eaten by the thousands who built the pyramids and temples, for the Egyptian priests believed like modern herbalists that these vegetables prevent epidemic disease, a view partially confirmed by modern scientists. At the least, these vegetables contain ingredients that have antibiotic properties. Other ingredients were less likely to be efficacious, such as Nile mud, dung, and urine. There was also a tendency to mix medicines into wine or beer; this contributed to a feeling of well-being in the patient.

Treatment of diseases with unknown causes was done strictly in a religious context. Egyptians believed that gods watch over each body part and priests devoted to a particular god were also specialists in treating that body part. Surgery for wounds and broken bones was quite different. The priests knew that the cause of these injuries was not the gods. A papyrus known as the Edwin Smith Surgical Papyrus (because it was purchased by American Egyptologist Edwin Smith) does not mention the gods, even though it dates from about 1550 BCE and is probably a copy of an earlier manuscript that may be as much as a thousand years older. The papyrus tells how to set bones, about the pumping function of the heart, and that the pulse can be used to determine how the heart is functioning. Another medical papyrus from about this time, the Papyrus Ebers, gives other medical practices, such as prescribing medications and diets.

Although Egyptian medicine went into decline about 1200 BCE, its reputation as the best in the ancient world continued until well after Egypt became a Roman province in 30 BCE.

Looms are depicted in Assyrian and Egyptian murals. *See also* 6000 BCE MATR; 1500 BCE TOOL.

The bellows is invented shortly after this date.

Balance scales are known from Egypt and Mesopotamia, although the evidence for such balances — consisting of drawings and paintings — is not sufficiently detailed to see how the scales are pivoted or whether they could be adjusted. *See also* 2400 BCE MATH; 1450 BCE TOOL.

The oldest known lock-and-key arrangement, carved from wood, is made in Mesopotamia. *See also* 400 BCE TOOL.

In Egypt the tools of war include a pointed battering ram that can be operated from a portable hut, for use in breaching walls of sun-dried brick while protecting the people operating the ram. *See also* 2500 BCE TOOL.

→ Transportation

Some roads in Crete are paved with stone. *See also* 600 BCE TRAN.

Rims around wooden wheels are frequently made from copper instead of a strip of wood as had been used previously. *See also* 3000 BCE TRAN.

According to Strabo, the Egyptians under Sesostris (known to the Greeks as Senusret I) build a canal from Lake Timsah (the Nile) to the Red Sea. It is not certain that this canal is completed, but if so it will later be sanded in. This precedes several versions of a canal begun by Pharaoh Necho and eventually completed by either Darius the Persian or Ptolemy II. *See also* 600 BCE TRAN.

People of the Sintashta-Petrokva culture living on the Russian steppes near the border with present-day Kazakhstan develop the first spoked wheels. The wheels have 8 to 12 spokes and are used on one-person chariots. *See also* 3000 BCE TRAN; 1800 BCE TRAN.

→ Transportation

The Egyptian fortress at Buhen in Nubia (southern Egypt and northern Sudan) has a drawbridge that moves on rollers. *See also* 850 BCE TRAN.

A picture from about this time shows 172 men moving a statue known to weigh 60 tons on a sled, with a man pouring liquid in front of the sled to make it slide more easily. *See also* 6500 BCE TRAN.

1950 BCE

Σ Mathematics

A copper bar from Nippur weighing 41.5 kg (91.3 lb) and 110.35 cm (43.44 in.) long is an early standard measure. It is divided into 4 measures of 16 parts each. *See also* 2000 BCE MATH.

1900 BCE

▲ Archaeology

The Minoan civilization on Crete begins to be powerful. Large palaces are built at Knossos, Phaestos, Malia, and Zakros. *See also* 6000 BCE ARCH.

▲ Construction

A mud-brick arch built by Canaanites in what later became the Philistine city of Ashkelon (Israel) is the oldest true load-bearing arch known.

The ruins of the arch will be discovered in 1992 CE. *See also* 2800 BCE CONS.

1850 BCE

▲ Construction

The Egyptian national water administration occupies a building south of Memphis that has about 3000 rooms. It is nicknamed the Labyrinth. Some of it is below ground and, according to Herodotus, contains the graves of kings and sacred crocodiles.

II Food & agriculture

An enormous irrigation project for the Fayum desert region is begun by Pharaoh Sesostris II and completed by Ammenemes II. A canal 90 m (300 ft) wide carries water from the Nile to a 1735-sq-m (670-sq-mi) natural depression in the Fayum. Flow of water is controlled by a dam with sluice gates. *See also* 6000 BCE FOOD; 1750 BCE FOOD.

Σ Mathematics

Mesopotamian mathematicians discover what is now known as the Pythagorean theorem. *See also* 2000 BCE MATH.

1800 BCE

▲ Archaeology

The sixth Amorite king of Sumer, Hammurabi, is born about this time. He is known for the Code of Laws, but he also vastly extends the empire based in Babylon. From this time and for many centuries thereafter, the Mesopotamian region is properly referred to as Babylonia instead of Sumeria. *See also* 1900 BCE ARCH; 1366 BCE ARCH.

↳ Communication

The wedge-shaped point on the stylus used for inscribing pictographs on clay tablets has by this time changed the writing style in Mesopotamia to an early form of cuneiform (which means “wedge-shaped”). The pictographs have become very stylized and might more properly be called ideograms. *See also* 3000 BCE COMM; 1500 BCE COMM.

II Food & agriculture

Jute is cultivated in India. *See also* 3000 BCE FOOD.

Σ Mathematics

Multiplication tables appear in Mesopotamia.

→ Transportation

People in Mesopotamia build wheels with spokes, using four perpendicular spokes for each wheel. *See also* 1900 BCE TRAN; 1600 BCE TRAN.

1750 BCE

▲ Archaeology

The Harappan civilization along the Indus River mysteriously comes to a close. *See also* 2300 BCE CONS.

The Shang dynasty in China begins on the floodplain of the Huang He (Yellow River), which is utilized for an irrigation system. *See also* 1850 BCE FOOD; 1100 BCE ARCH.

↳ Communication

The famous Code of Hammurabi, the first known set of laws, is written.

II Food & agriculture

In the Rimac Valley of Peru, near a temple and settlement now known as La Florida, vil-

lagers construct a canal that is between 4 km (2.5 mi) and 10 km (4 mi) long. It quadruples the amount of arable land in the region. *See also* 2400 BCE FOOD.

Σ Mathematics

The Moscow papyrus, dating from the Twelfth Dynasty, shows that the Egyptians possess an extensive knowledge of geometry, the most sophisticated being a formula for the volume of a truncated pyramid. The Moscow and Rhind papyri are the two main sources of knowledge of Egyptian mathematics. *See also* 1650 BCE MATH.

1700 BCE

Ἁ Archaeology

The Hittites, a group of Indo-European speakers from the mountains between the Black Sea and the Mediterranean, move into the plains of Anatolia (Turkey). *See also* 1372 BCE ARCH.

♥ Medicine & health

An Egyptian papyrus by an unknown physician describes the brain's general anatomy — the first written record about the brain. *See also* 2500 BCE MED; 1550 BCE MED.

1650 BCE

Σ Mathematics

Ahmes (also known as Ahmose), an Egyptian scribe, writes *Directions for Attaining Knowledge of All Dark Things*, better known as the Rhind papyrus, first discovered in 1858 and then purchased by a Scot named Henry Rhind. Ahmes notes that he is copying material that is about 200 years old. The manuscript contains 85 problems and their solutions, most based on arithmetic, but a few concerning geometry. *See also* 1750 BCE MATH; 1200 BCE MATH.

1645 BCE

🌐 Earth science

The volcanic island of Thera, now the largest island in the Santorini group of Cyclades islands, erupts, as dated by glacial cores found in Greenland in the 20th century. This eruption, which probably destroys the nearby Cretan civilization, had earlier been placed at 1550 BCE, but the ice-core date is also matched with radiocarbon dates on the island itself that cluster in the range 1690 to 1620 BCE. The eruption may also account for unusually harsh winters from 1626 to 1628 BCE as recorded in the rings of ancient bristlecone pines.

Santorini and Atlantis

We know from geological and archaeological records that a major eruption of the volcano Thera (named after the largest remaining island in the Santorini group, which surround the caldera caused by Thera's explosion) took place about 3500 years ago. Radiocarbon, tree-ring, ice-core data have shown that the date was probably between 1690 and 1620 BCE. This eruption has been blamed for everything from the destruction of the Minoan civilization to the legend of Atlantis to the parting of the Red Sea by Moses. Chinese records speak of yellow fogs, cold weather, and floods now thought to have originated in the blast. The volcano continues to be active. It erupted as recently as 1950 and six years later a major earthquake in the region killed scores of islanders.

Thera is in the Mediterranean Sea, only 120 km (70 mi) from the island of Crete. The people who lived in Crete, starting about 2600 BCE, are known today as the Minoans, after King Minos, their legendary ruler. Shortly after 1400 BCE, according to archaeologists, the powerful Minoan civilization vanished and was replaced by a simple peasant culture. One theory holds that earthquakes associated with the Santorini eruption caused extensive damage to the Minoan palaces, especially from fires from lamps that were knocked over; a more recent theory credits the shock wave from the blast as overturning the lamps. The discrepancy between the date of the major eruption of Thera and the end of the civilization, with the eruption dated by geochemical

and biological means but the end of the Minoans dated by linking pottery styles in Crete to pottery well-dated by written records in Egypt, is hard to reconcile. The volcanic eruption of the 17th century BCE caused tsunamis 9 m (30 ft) high in Crete and dropped 10 cm (4 inches) of ash on the island, but the fires apparently destroyed the palaces.

Atlantis was supposed to have been a large island west of the Strait of Gibraltar, in the Atlantic Ocean. Legend has it that Atlantis was the leading civilization of its time. Plato, whose two descriptions are the main source of the legend, wrote that "in a single day and night of misfortune, it sank into the sea." Some scientists think that Atlantis was a large island where the Santorini group is today — a theory first proposed in 1872. When the great eruption happened, the large island and everyone on it vanished. Today the former large island is the caldera filled with the sea. Another theory, which dates from 1909, is that Atlantis was Crete itself, which lost a great civilization, although the island was not replaced by the sea as Thera was.

Other stories from the Bronze Age have also been connected to the Thera eruption by various authors:

- A Greek flood myth, perhaps inspired by Thera's tsunamis.
- Various events in the story of Jason and the Argonauts.
- The seven plagues of Egypt foretold by Moses, as well as the pillar of cloud by day and fire by night that led the Exodus.

These all have plausibility, although each would be difficult to prove.

1600 BCE

1600 BCE

★ Astronomy

Astronomers in Mesopotamia identify the constellations of the Zodiac, those through which the Sun moves each year. *See also* 3000 BCE AST.

■ Construction

The last pyramid tombs of the pharaohs of Egypt are built. Some authorities think Pharaoh Ahmose I builds the last one. *See also* 2575 BCE CONS; 210 BCE ARCH.

❖ Materials

Bellows are used in the manufacture of glass and in metallurgy. *See also* 2000 BCE MATR; 1500 BCE MATR.

→ Transportation

Wheels with spokes are in use in Egypt. *See also* 1800 BCE TRAN; 1500 BCE TRAN.

1550 BCE

♥ Medicine & health

The Edwin Smith Surgical Papyrus is written, although it appears to be a copy of a manuscript written about 2500 BCE. The papyrus is a scientific treatise on surgery. *See also* 1700 BCE MED.

The Papyrus Ebers gives a description of 700 medications. It also shows that physicians prescribe diets or fasts and massage, and that some practice hypnosis. *See also* 1700 BCE MED.

1500 BCE

★ Astronomy

Thutmose III erects in Heliopolis the so-called

Cleopatra's Needle. Its shadow is used to calculate time, season, and solstices. *See also* 1450 BCE CONS.

■ Communication

One of the first alphabets is developed in Ugarit (Syria) by stripping down Mesopotamian cuneiform characters to only 30 signs. Each sign stands for a different sound. Elsewhere in the Middle East scribes develop alphabets using symbols that are easier to write on papyrus than the wedge-shaped letters of cuneiform script. *See also* 1800 BCE COMM; 1000 BCE COMM.

■ Construction

One of the earliest monumental building sites in the Americas, known as El Paraíso or Chuquitanta (coastal Peru), consists of 13 or 14 collapsed platforms about 2 km (1.25 mi) from the Pacific. It is made from about 90,000 metric tons (100,000 short tons) of quarried rock thought to have been part of temples before their collapse. One platform measures about 50 m (160 ft) on each side.

■ Food & agriculture

Bone inscriptions in China refer to the brewing of beer. Liquor is distilled in parts of Asia. *See also* 6000 BCE FOOD.

The first professional millers appear about this time in Egypt. Previously all grain was ground on hand mills of various design at home. *See also* 6000 BCE FOOD; 1100 BCE TOOL.

The soybean is cultivated in Manchuria.

The Sumerians invent the sin-

gle-tube seed drill. *See also* 2000 BCE FOOD; 100 CE FOOD.

The dingo, a semidomesticated dog, arrives in Australia from Indonesia. *See also* 8400 BCE FOOD.

The beam press, which uses a lever action to press the liquid from substances such as olives and grapes, is invented in the Aegean region. *See also* 3000 BCE FOOD.

❖ Materials

Glass begins to be shaped while in its hot plastic state. Previously, glass had been worked after it cooled, as if it were a rock. *See also* 1600 BCE MATR.

Artisans in the Near East develop the art of lost-wax casting in which a wax "positive" is encased in a clay "negative." When hot metal is poured into the clay outer coat, the wax melts and runs out, being replaced by the metal. By using a wax covering over a "positive" core which is then coated with a "negative" of clay, the need for expensive metal is minimized. The core can be removed, resulting in a hollow metal casting.

Beads of Egyptian faience are found all over Europe as a result of a thriving trade network that imports the beads from manufacturing centers in the Near East. *See also* 3000 BCE MATR.

Iron smelting — that is, producing the metal from its ore — begins a period of improvement, mainly in the Mitanni kingdom in Armenia and under the people who later conquer the Mitanni, the Hittites. The main secret of the Mitanni process is further

heating and hammering, a technique not needed for bronze but absolutely necessary for iron. *See also* 2200 BCE MATR; 1400 BCE MATR.

From the archaeological record, bone tools, such as needles, awls, and reamers, which had been common in Tasmania 3500 years earlier, have by now vanished completely after a long decline in use. *See also* 19,000 BCE MATR.

I Tools

The earliest known fragment of a sundial dates from this time in Egypt. *See also* 620 BCE TOOL.

The Chinese make a treadle-operated loom. *See also* 2000 BCE TOOL.

→ Transportation

Light carts with two spoked wheels are used in warfare. *See also* 1600 BCE TRAN; 1300 BCE TRAN.

1450 BCE

■ Construction

A 32-m- (105-ft-) tall obelisk is made for Pharaoh Thutmose III, the largest from ancient times. It stands today at the Church of San Giovanni in Laterano in Rome. Obelisks are tapering granite shafts capped with small metal-coated pyramids (pyramidions) that reflect the rays of the sun god that the obelisks are supposed to honor. However, most obelisks were erected with inscriptions boasting of the feats of the ruler who had them built, not prayers to the god. *See also* 1500 BCE AST.

Stonehenge achieves the form

in which it is known today. *See also* 2200 BCE CONS.

I Tools

The use of a balance with a pointer for weighing is developed in Egypt. *See also* 2000 BCE TOOL.

→ Transportation

Barges about 60 m (200 ft) long, constructed for carrying obelisks, such as the 32-m (105-ft) one made for Thutmose III, are the largest ships to this time. *See also* 2450 BCE TRAN; 1400 BCE TRAN.

1401 BCE

■ Archaeology

The first effort to restore the Egyptian Sphinx is conducted. During Antiquity there will be two more efforts to return it to its original splendor. *See also* 2600 BCE ARCH.



THE SPHINX Efforts to restore the ancient stone statue have often resulted in more damage—but the nose was lost due to target practice by Napoleon's soldiers.

1400 BCE

■ Archaeology

In the rain forests along the west coast of the Gulf of Mexico the Olmec civilization starts. *See also* 1250 BCE CONS.

II Food & agriculture

Multiple cropping within the same year is in use in China.

♦ Materials

Dorian invaders from the north with iron weapons conquer the Minoans, who have only bronze tools. *See also* 1500 BCE MATR; 1370 BCE MATR.

→ Transportation

At this time, as we know from remains of early shipwrecks, seagoing ships in the Mediterranean are built by first joining planks together to make a hull. *See also* 1450 BCE TRAN; 1025 tran.

1380 BCE

I Tools

An Egyptian water clock, or clepsydra, made from alabaster, is known from this date. The Egyptians had probably been using such clocks since about 1450 BCE. *See also* 1500 BCE TOOL; 200 BCE TOOL

1370 BCE

♦ Materials

The Hittites obtain the secret of making usable iron by heating and hammering it when they conquer the Mitanni kingdom in Armenia. *See also* 1400 BCE MATR; 1286 BCE MATR.

The Egyptians and Mesopotamians produce glass. A

glassworks from about this time at Tel-el-Amarna will be discovered by Flinders Petrie in 1894.

1366 BCE

■ Archaeology

King Suppiluliuma of the Hittites conquers much of northern Mesopotamia and the region west of Mesopotamia (Syria) almost to Egypt. *See also* 1800 BCE ARCH.

1365 BCE

■ Archaeology

Pharaoh Amenhotep IV ascends the throne of Egypt. With his wife Nefertiti he promotes monotheistic worship of the sun disk Aten, even changing his own name to Akhenaten (the spirit of Aten). *See also* 1260 BCE CONS.

1350 BCE

C Communication

A wooden torso left in the tomb of Pharaoh Tutankhamen (Egypt) at this time is the earliest known clothing dummy and the ancestor of the fashion mannequin.

■ Construction

Tree-ring dating shows that a large platform constructed of oak in the shallow waters of Flag Fen (near Peterborough, England) is built about this time. The platform is built on an artificial island and surrounded with a boardwalk. At one end, bronze tools appear to have been thrown into the fen as sacrifices. Although the purpose of the platform is not certain, it is thought that it guarded access to land

claimed by the builders for farming.

♦ Materials

Pots of perfume sealed in the tomb of the Pharaoh Tutankhamen in 1352 BCE are still fragrant when opened in 1922, the product of the powerful perfume industry in Egypt. *See also* 2000 BCE MATR.

→ Transportation

A freighter loaded with 10 tons of copper in more than 350 ingots, as well as tin, a ton of resins used in making perfume, blue glass disks, and scrap gold and silver, as well as miscellaneous treasures, such as hippopotamus teeth, amber, tortoise shells, and ostrich eggs, is wrecked at what we now call Ulu Burun on the south coast of Asia Minor (near Kas, Turkey). *See also* 1982 CE ARCH

1300 BCE

★ Astronomy

Chinese astronomers establish that the length of the year is 365½ days.

■ Construction

A stone-filled dam faced with basalt blocks about 150 m (500 ft) long and 6 m (20 ft) high is built at the northern end of a low, flat valley called Orontes during the reign of Egyptian Pharaoh Seti I. It creates the Lake of Homes that is 5 m (17 ft) deep, and which persists even today. *See also* 2500 BCE CONS.

→ Transportation

Spokes for wheels, first used in Mesopotamia around 2000 BCE, are in use in China. *See also* 1500 BCE TRAN.

1286 BCE

1286 BCE

❖ Materials

The Hittites use their superior iron weapons in war with the Egyptians. This gives the Hittites an advantage but also makes the Near Eastern world aware of the potential of iron. Soon the Hittite secrets of manufacture are found out by others. *See also* 1370 BCE MATR; 1250 BCE MATR.

1285 BCE

■ Construction

By the time of Ramses II Egyptian construction crews are able to move statues weighing as much as 1000 tons from place to place. *See also* 2490 BCE CONS.

1260 BCE

■ Construction

The huge temple of Abu Simbel on the Upper Nile in Egypt is built in honor of Ramses II. Cut out of the living rock, Abu Simbel is sited so that on two days of the year (one in mid-October and the other in mid-February) the sun illuminates the inner sanctuary. The dates are thought to have been chosen to commemorate famous military victories of Ramses II. *See also* 1365 BCE ARCH.

1250 BCE

★ Astronomy

The Babylonians develop an instrument that can determine when a star or planet is due south. *See also* 2575 BCE CONS; 1050 BCE TRAN.

■ Construction

The Olmec build one of the first large ceremonial centers in the Americas at a place on the Gulf of Mexico now known as San Lorenzo. It is constructed on a large raised platform, 54 m (150 ft) high, made by pouring many baskets of clay into a frame built with logs. *See also* 1400 BCE ARCH; 900 BCE ARCH.

❖ Materials

Ironworkers are reported in Jaffa (Palestine), suggesting that the Hittite secrets for making iron are leaking out. *See also* 1286 BCE MATR; 1185 BCE MATR.

1200 BCE

■ Archaeology

In a campaign commemorated about 850 BCE by Greek bard Homer, the Mycenaeans from Greece lay siege to Troy (Turkey). *See also* 1800 BCE ARCH; 1183 BCE ARCH.

↗ Energy

Ducts beneath the floors of the palace of the King of Arzawa, built about this time in southwestern Anatolia (Turkey), suggest that the palace had central heating. Not only is this the earliest known evidence of central heating, but there is no other evidence of the practice for the next thousand years. *See also* 40,000 BCE ENER; 900 BCE ENER.

❖ Materials

Iron is in common use throughout the Near East, so 1200 BCE is commonly taken as the beginning of the Iron Age for this region, although iron has been known for mil-

lennia. *See also* 4000 BCE MATR; 1185 BCE MATR.

Bells cast in bronze appear in China.

Σ Mathematics

It can definitely be established that Egyptian surveyors use a 3-4-5 right triangle to establish right angles, but the account of Greek historian Herodotus puts this practice back at least as far as 1850 BCE. The construction of unusually good right angles in the major pyramids suggests that the method may go back to before 2500 BCE. *See also* 1850 BCE MATH; 600 BCE MATH.

I Tools

Mesopotamians build devices that convert rotary motion into a back-and-forth motion.

→ Transportation

A small freighter loaded with copper and bronze is wrecked at what we now call Cape Gelidonya on the southwest coast of Asia Minor (Turkey). *See also* 1960 CE ARCH.

1185 BCE

❖ Materials

Despite their iron weapons, the Hittites are conquered by the Peoples of the Sea (probably Indo-European speakers, such as the Phrygians), and the Hittite secrets of iron-working spread even farther. *See also* 1250 BCE MATR.

1183 BCE

■ Archaeology

According to tradition, Troy falls to the Mycenaean Greeks.

See also 1200 BCE ARCH; 1140 BCE ARCH.

1140 BCE

❖ Archaeology

Dorian invaders begin driving out the indigenous tribes of Epirus and Thessaly and then replacing the Mycenaeans throughout Greece, a process that is complete by about 1000 BCE. *See also* 1200 BCE ARCH.

1100 BCE

↗ Energy

People in Europe and western Asia use lamps that burn olive or nut oil with vegetable-fiber wicks. *See also* 40,000 BCE ENER.

❖ Materials

The Assyrians capture iron-making centers when they invade what is now Armenia. Still, it is not until 900 BCE that the formidable Assyrian army is re-equipped with iron weapons. *See also* 1200 BCE MATR; 1000 BCE MATR.

I Tools

The rotary quern, or rotary hand mill, is invented for grinding grain. It replaces the saddle quern, a form of mortar and pestle. A handle is used to rotate one stone that is placed on top of a stationary stone. This device is the ancestor of the large mills operated by animal, water, or wind power that began to be built in Europe in Hellenistic and Roman times. *See also* 1500 BCE FOOD; 800 BCE TOOL.

→ Transportation

The basic chariot of Mesopotamia is redesigned, using wheels with six spokes instead

of four and with the axle moved from the middle of the chariot to a position at the rear. Both changes result in a chariot that can travel better over rough ground. *See also* 1500 BCE TRAN.

1050 BCE

→ Transportation

The Duke of Chou in China builds either an early “south-pointing carriage” or magnetic compass (a south-pointing carriage uses a differential gear to keep a part of the carriage pointing in the same direction no matter which way the carriage turns). *See also* 260 CE TRAN.

1000 BCE

↳ Communication

A map on a clay tablet shows the world with Babylon as its center. *See also* 2300 BCE COMM; 600 BCE ARCH.

The Phoenicians develop their alphabet of 22 signs for consonants. Although not the first alphabet, it is the one adapted by both Greeks and Israelites to their own needs, giving birth eventually to the Roman alphabet that is used in most Western nations today. The oldest known inscription in the Phoenician alphabet is made at Byblos (in Lebanon). *See also* 1500 BCE COMM.

¶ Construction

According to a clay tablet from Moab (Jordan), the ruler Mesho builds two aqueducts to supply the city of Karcho in Moab. This is the earliest known reference to the use of aqueducts to supply water. *See also* 690 BCE CONS.

¶ Food & agriculture

Several food preservation techniques exist in China: salting, use of spices, drying and smoking, and fermentation in wine (vinegar). *See also* 1500 BCE FOOD.

Reindeer are domesticated in the Pazyryk Valley of Siberia (Russia). *See also* 2500 BCE FOOD.

Oats are cultivated in central Europe.

❖ Materials

Dyes made from the purple murex, a Mediterranean shellfish, are introduced by the Phoenicians. Production of the dye is very costly, and cloth dyed purple becomes associated with royalty. *See also* 80,000 BCE COMM; 1548 BCE MATR.

Iron objects begin to appear in graves in Greece and Crete. *See also* 1100 BCE MATR.

Shortly before this time Mesopotamian craftspeople begin using lead glazes on bricks and tiles. *See also* 3000 BCE MATR.

Lead is recognized as a metal, although people at this time have no particular use for it. *See also* 2500 BCE MATR.

Σ Mathematics

Chinese counting boards originate. *See also* 3000 BCE MATH.

♥ Medicine & health

Etruscan goldworkers are the earliest known to make dental bridgework, mostly for cosmetic purposes. *See also* 3000 BCE MED.

→ Transportation

The Phoenicians begin their exploration and colonization

of the shores of the Mediterranean by building a port at Tyre (Lebanon). The region between two small offshore islands is filled with rubble, connecting them into a single island. Sea walls are built to form two harbors. *See also* 814 BCE ARCH.

Proto-Polynesian stone tools found in Fiji are made of obsidian from the island of New Britain 4500 km (2800 mi) to the west, indicating the existence of long-distance trade routes. *See also* 2550 BCE TRAN.

900 BCE

↗ Energy

Natural gas from wells is used in China. *See also* 1200 BCE ENER.

❖ Materials

Iron objects begin to appear in Italy among the people called Villanovan. Iron objects are also left in graves in Greece and Crete. *See also* 1000 BCE MATR; 700 BCE MATR.

850 BCE

¶ Archaeology

The first great civilization of South America, known today as the Chavín, which arose in the north, reaches the central Andes of Peru and establishes itself in the region, possibly by conquest but also possibly as a result of a religious revival. *See also* 1500 BCE CONS.

¶ Construction

The first known arched bridge is built in Smyrna (Izmir, Turkey). *See also* 2000 BCE TRAN; 600 BCE CONS.

The 14-m-high (45-ft-high) Chavín de Huantar temple, now called the Castillo is begun near the continental divide (Peru). Over a period of 500 years it is completed with several levels of interior galleries. It is built with stones without mortar with ceilings partially supported by cantilevered stones projecting from the walls. The earliest known stone edifice in South America, it is about 75 m by 72 m (245 ft by 235 ft) square at its base. Vents bring air into the interior rooms, and a system of canals and conduits carries water from a nearby river through the temple. *See also* 1500 BCE CONS.

→ Transportation

The ram is added to warships by the Greeks or possibly by the Phoenicians. Previously, the only naval strategy had been to board an enemy ship and fight hand to hand. With the ram, it becomes possible to sink enemy vessels. *See also* 1400 BCE TRAN; 700 BCE TRAN.

814 BCE

¶ Archaeology

According to tradition, Carthage is founded in North Africa by the Phoenicians. Various pieces of evidence confirm that a date around 800 to 850 BCE is likely. *See also* 1000 BCE TRAN; 800 BCE TRAN.

800 BCE

¶ Construction

The Olmec build pyramids in La Venta (Tabasco, Mexico). *See also* 900 BCE ARCH; 650 BCE COMM.

I Tools

Querns with what appear to have the first known form of crank operation appear in the Near East (Syria). A peg is inserted into a hole drilled near the outer edge of the upper stone of a rotary quern, enabling the user to turn the stone in a continuous motion by moving the peg in a circle. Previous querns used radial spokes (for mechanical advantage), but the peg handle is about a dozen times as efficient. True crank handles are invented several hundred years later by the Chinese. *See also* 1100 BCE TOOL; 100 BCE TOOL.

→ Transportation

Phoenicians exploring the Atlantic Ocean's European shore establish Gadir (Cadiz, Spain) as the farthest western end of their trade route. *See also* 814 BCE ARCH; 600 BCE TRAN.

776 BCE

▲ Archaeology

According to tradition, the Olympic Games are started with a single event, a foot race of one stade (about 200 m or 650 ft).

753 BCE

▲ Archaeology

According to tradition, Rome is founded on April 21 on the banks of the Tiber by Romulus.

750 BCE

← Communication

The Phoenician alphabet reaches Attica in Greece and is quickly adapted to the Greek

language. Traditional poetry, such as that of Hesiod and Homer, composed perhaps a hundred years earlier, is written down for the first time. *See also* 1000 BCE COMM; 740 BCE COMM.

720 BCE

★ Astronomy

In the Chou dynasty of China, a series of 36 records of solar eclipse begins.

740 BCE

↳ Communication

The Greek alphabet begins to emerge as a separate entity from Phoenician, appearing on artifacts known from Athens, Phrygia (in central Turkey), and Ischia (in the Bay of Naples, Italy). *See also* 750 BCE COMM.

700 BCE

↳ Communication

The first standard coinage is in use in Lydia (western Turkey), reputedly issued by King Croesus.

■ Construction

Rebuilt after a fire late in the seventh century, a five-story, 33-m (107 ft) pagoda dominates the Buddhist temple at Hōryūji near Nara, Japan.

Hezekiah's Tunnel is built as part of the waterworks for Jerusalem, primarily to provide water during an anticipated siege. Two teams had worked from opposite ends of the tunnel, but modern research suggests that they widened and straightened a natural passageway through the limestone that underlies

the city rather than working through unbroken rock. *See also* 2200 BCE CONS; 522 BCE CONS.

II Food & agriculture

Incubators are used in Egypt to hatch chicken eggs. *See also* 7000 BCE FOOD.

In Assyria (Iraq) the practice of digging underground tunnels, called qanats, to subterranean aquifers for irrigation purposes begins. The Romans and Arabs later spread this practice to the Mediterranean region. *See also* 1750 BCE FOOD.

◊ Materials

A large-scale iron-manufacturing center grows up at what is now Hallstatt, Austria; another such center is in Meroë, Nubia (Sudan). *See also* 900 BCE MATR.

Glaucus of Chios invents soldering with an alloy that melts easily. *See also* 2500 BCE MATR.

♥ Medicine & health

In Greece, patients are treated at temples of the god Asklepios, whose staff with entwined serpents is still used as a symbol of medicine.

I Tools

The true potter's wheel that can be rotated continuously is introduced. *See also* 3500 BCE TOOL.

The Assyrians use a sort of pulley. *See also* 390 BCE TOOL.

Water clocks begin to be used in Assyria.

→ Transportation

The Phoenicians (or possibly the Greeks) introduce war galleys that have two banks of oars (biremes). These are

more compact, sturdier, possibly more seaworthy, and less of a target to opposing rams, since the same number of rowers are used as in previous warships with single banks of rowers. One school of modern thought suggests that since the length of the ship is not increased by the Phoenicians, the bireme is top-heavy and easily capsized. *See also* 850 BCE TRAN; 650 BCE TRAN.

690 BCE

■ Construction

King Sennacherib of Assyria builds several aqueducts to supply Nineveh, mostly in the form of open canals. The most remarkable carries water about 48 km (30 mi) to an artificial reservoir formed by damming the Tebitu River from another river, the Gomel. The canal is 19.8 m (65 ft) wide and at one point raised on corbeled arches 9.8 m (30 ft) for 274.3 m (900 ft) so it can cross a stream. The bottom of the canal is a 40-cm (16-in.) layer of concrete on a 2-cm (1-in.) layer of mastic (bitumen mixed with sand), with the concrete made from one part lime, two parts sand, and four parts aggregate. *See also* 1750 BCE FOOD; 522 BCE CONS.

650 BCE

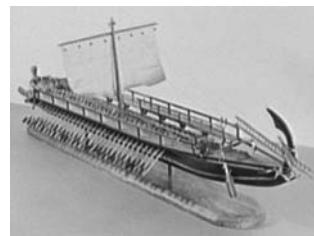
↳ Communication

The Olmec of the Gulf Coast of what is now Mexico become the "mother civilization" of Mesoamerica (Central America and what is now Mexico). In particular, they bequeath a numeration system and calendar that they devise, as well as the beginnings of written language, to

the Maya. Later the Aztec use a simplified form of the calendar. The first signs of a written Olmec language, a large cylindrical seal and a broken jade plaque, date from this time. *See also* 3114 BCE AST.

→ Transportation

An unknown Greek naval architect designs a ship with a lateral projection above the gunwale that provides room for a third bank of oars. The result, called a trireme, becomes the common military vessel throughout the early classic period. Because it has



TRIREME The trireme was the first warship of the Mediterranean sea, powered by sails when there was wind and by files of rowers when there was no wind or when in battle. Note that there was no rudder; the paddle at the front was used for steering.

640 BCE

→ Transportation

The Greeks build a ship canal across the peninsula of Leukas (Levkás), which today is an island in the Ionian Sea. *See also* 1900 BCE TRAN; 600 BCE TRAN.

612 BCE

▲ Archaeology

The Assyrian Empire collapses. *See also* 690 BCE CONS.

three banks of oars, providing for 170 rowers in all, instead of two banks, but is otherwise the same length and breadth, the trireme is both speedier and more maneuverable than naval

vessels that preceded it. Some sources claim the trireme was invented in 704 BCE by Ameinokles of Corinth, but this seems to be too early. *See also* 700 BCE TRAN.



Science and Technology in Antiquity: 600 BCE through 529 CE

Science that presents an organized view of the universe developed with the rise of Greek civilization, starting about 600 BCE. The Greeks developed institutions, such as the Academy, the Lyceum, and the Museum, that pursued science in somewhat the way the universities do today. When the Academy and Lyceum were closed in 529 CE, and the Museum was destroyed about the same time, the Greek era in science was over, although Greek writings continued to have great influence for another thousand years or more. This period, from the birth of Western civilization in Europe to the start of what is often called the Dark Ages, can be termed “Antiquity”—for example, to say that the metal tin was “known in Antiquity” implies that it was known at this time.

The earliest Greeks, descendants of warriors that invaded the Greek peninsula around 1400 BCE, were seafarers and traders. Their need for navigation skills was an important factor in predestining the Greeks to practice science, especially geometry. Scholars from the Egyptian and Mesopotamian civilizations already had learned many scientific results before the start of Greek civilization, but these were mainly observations and recipes for specific applications. Although the Egyptian Imhotep might be claimed as a scientist for his knowledge of medicine and architecture, the Greeks were the first to believe that humans could understand the universe using reason alone rather than through mythology or religion. They searched for explanations for all natural phenomena. No personal forces or gods were involved, only impersonal,

natural processes. These early searchers are often termed philosophers rather than scientists, however, since few are known to have performed specific experiments. However, the early Greek philosophers — Thales, Anaximander, and Anaximenes — were the first to look for general principles beyond observation. And some of the Greek philosophers, including Pythagoras, Aristotle, and Archimedes, are known to have performed experiments.

Philosophy, a precursor to science

Greek science and mathematics begins with the Ionian school of natural philosophy shortly after 600 BCE, so called because it originated in Miletus, a city-state on the coast of what is now Turkey, then a Greek region called Ionia. Thales of Miletus is regarded as the founder of the Ionian school. He probably studied in Egypt, where he was exposed to new ideas. It is likely that there he learned the craft of land surveying, from which he deduced geometry. In Mesopotamia he studied astronomy, and it is believed that he predicted a solar eclipse. Thales began the search for a unifying principle or essence underlying all phenomena and identified this essence as water.

Anaximander was a pupil of Thales. He is believed to have written the earliest scientific book, now lost. Anaximander formulated a theory of the origin and evolution of life. He believed that life originated in the sea from the “moist element,” which was evaporated by the Sun. The presence of shells and marine fossils was for him the proof that the sea covered much of Earth’s surface. He postu-

lated that humans must have originated in the sea and have originally resembled fish. Anaximenes continued the search for a basic principle, which as his ideas passed through several philosophers gradually came to be the four elements of fire, air, earth, and water (with Aristotle adding a fifth element, quintessence, for the heavens). This search was the earliest version of the quest for a Theory of Everything, which continues to be an important part of theoretical physics today. One difference is that today’s proposals for a Theory of Everything are not accepted by other scientists until they can be established by predicting correct and measurable results.

Ionian philosophers and their followers, therefore, introduced the earliest form of scientific method, which was based on reasoning and observation with very little experimentation. They developed differing theories about the causes of natural phenomena and the nature of matter. The atomists, such as Leucippus and Democritus, believed reality to be embodied in matter, while the Pythagoreans viewed the universe as form and number. Our knowledge of such theories is fragmentary and often available only from material written hundreds of years after the original ideas. In many instances the only source is someone writing in opposition to the original idea, almost guaranteeing a simplistic and distorted view of it.

Two teachers, Plato, heavily influenced by the Pythagoreans, and Aristotle, who relied more on observation, became central to Greek science. Both led schools in Athens more than 200 years after Thales. Plato’s Academy promoted a pure form of mathematics.

Aristotle, whose school was the Lyceum, became the most important scholar in Greek Antiquity. He introduced the inductive method, a version of the scientific method that still plays a role in scientific thinking today. This method consists of deducing general principles from observations of phenomena and then using these general principles to explain other observations.

The Hellenistic world and the Roman Empire

Greek colonies were planted around the Mediterranean Sea, and many who were not Greek themselves turned to the Greek language and adopted Greek ways. This larger Greek culture is called Hellenistic after the Greek word for their own people (as opposed to others, called barbarians). Alexander the Great, a Hellenic Macedonian tutored by Aristotle, conquered the world from Greece to India in the fourth century BCE. The spread of Hellenic culture and science was one result. Hellenism became particularly strong in Egypt, especially in Alexandria.

The center of Greek culture moved to Alexandria after Roman rule became predominant with the occupation of Greece in 146 BCE. Most of the later Greek scientists and mathematicians of this period lived or at least studied in Alexandria, including Euclid, Archimedes, Ptolemy, and Eratosthenes.

After the third century CE, Hellenistic science went into decline. The rise of the Christian Church, which associated science with heathenism, amplified this process — the largest library at the time, the Library of the Temple of Serapis in Alexandria, was destroyed in 390 CE, and the Alexandrian mathematician Hypatia was murdered for her “pagan” ideas in 415 CE.

The Roman Empire is notorious for its limited number of advances over such a long period of time, especially

when compared with Greek and Hellenistic science. Indeed, there was almost no Roman science as such. It should be kept in mind, however, that many Hellenistic advances occurred under Roman rule.

When it comes to technology in Europe it can be argued that more happened in the half-millennium after the fall of the Roman Empire than during the half-millennium that the Empire existed. One important mechanical advance was the development of gears.

Other cultures of the period

At the beginning of this period, Egypt and Babylon were still powerful and centers of intellectual life. Most of the early Greek philosophers are thought to have studied in either Egypt or Mesopotamia — some perhaps even as far away as India. Both Egypt and Mesopotamia embraced Greek culture after the conquest by Alexandria.

Although the main thread of Western civilization runs through Greece and Rome, there were contemporaneous advances in other parts of the world. Early in the period, before Alexander’s empire, the Persian Empire had the resources to build some remarkable canals and bridges, but its most useful invention was a bow made from horn that was more practical than the wooden bow. Four regions that produced essentially separate civilizations were China, India, Mesoamerica, and the coast of Peru. In Mesoamerica, civilizations that descended from the Olmec of eastern Mexico flowered with the Maya of Central America. Both Chinese and Maya societies developed sophisticated mathematics, including the concept of place value, and had a strong tradition of observational astronomy. Chinese astronomers began to compile star maps 400 years before the first Hellenistic versions, but they did not develop a complete theoretical

basis for astronomy as the Greek astronomers did. The Peruvian coastal cities excelled in crafts and monumental construction, but did not develop writing.

Chinese technology surpassed the Romans in agriculture, materials, and invention. In agriculture the methods used for harnessing animals, rotating crops, and eliminating pests with chemicals or biological controls were introduced. Chinese canals linked their empire, and the Great Wall remains an example of the magnitude of Chinese construction. The first form of paper was invented in China before the start of the Roman Empire. The Chinese developed cast iron and built iron bridges and other structures. Porcelain was among other Chinese materials unknown in the West. The inventions of the compass and ship’s rudder revolutionized navigation. On a more domestic note, the Chinese introduced both the wheelbarrow and umbrella. Near the end of Antiquity, Chinese culture was introduced to Japan.

In North America the Mound Builders flourished in what is now the Midwest and Southeast of the United States, while in the Southwest the Anasazi began to build giant apartment complexes in canyons. These civilizations, while not as advanced in some ways as those of Mesoamerica, shared many of the same traits and technology. The mounds of the Mound Builders resemble the temple-platform pyramids of Mesoamerica, for example, and all used the same domestic plants and animals.

In the South Pacific, the Polynesians were able to navigate great distances between islands. Their basic culture failed to progress much beyond designing and building their outrigger canoes, perhaps because life on the islands was too easy to present many challenges. The Polynesian-based culture of Easter Island, with its mysterious statues and

inscriptions, did not really get started until after this period.

Major advances

ASTRONOMY Although the Greeks were less accurate observers of celestial events than the Babylonians, they developed a multitude of cosmological models. Thales assumed Earth to be floating in water, while Anaximander believed Earth to be a disk suspended freely in space. The Pythagoreans believed that Earth is a sphere in space. Eudoxus of Cnidus proposed that stars are attached to a larger sphere that rotates around Earth. The idea of the universe as nesting spheres came to be generally accepted in Greek and Hellenistic philosophy, with Earth at the center of the universe. Although challenged by Aristarchus of Samos, who proposed that the Sun is at the center of the universe, the geocentric universe was universally accepted until the Renaissance.

Despite their incorrect models, Hellenic astronomers, such as Eratosthenes, Hipparchus, and Ptolemy, correctly calculated the size of Earth and the distance to the Moon. An explanation of planetary motion developed by Hipparchus and refined by Ptolemy dominated astronomy until it was replaced by the system of Copernicus, Kepler, and Newton.

Many Greek writers correctly identified the nature of the Sun, Moon, and planets as well as the causes of eclipses, phases of the Moon, and other celestial events. But the observational science of this time could not establish whose theories were right and whose wrong, so most of the better guesses lost out in popularity to guesses that are now known to have been incorrect.

BIOLOGY Aristotle was the first to undertake the classification of living organisms on a grand scale, covering the range from the most imperfect

(plants) to the most perfect (man) — as he perceived the hierarchy. He separated animals into those with blood (vertebrates) and those without blood (invertebrates). He also divided the animals with blood into fish, amphibians, reptiles, birds, and mammals, a classification scheme that continues to work today. His anatomy was often good, but sometimes far wrong; he believed that the heart was the center of intelligence, for example. He observed and described the development of embryos, becoming the founder of comparative embryology. His main discovery was that the contribution of the mother is as important as that of the father. Before Aristotle, the common Greek notion was that man supplied the seed and that the role of the woman was similar to the role of soil in relation to the growth of a new plant.

Aristotle's successor as head of the Lyceum, Theophrastus, advanced biology and classification further, especially with regard to plants. Later biological insights during this period, however, were in anatomy as a result of dissections of animals and, rarely, human cadavers.

COMMUNICATION Systems for sending signals rapidly over long distances that were developed during this period may have been important to armies and empires, but perhaps Antiquity's greatest advance in communication was the creation of the Library at Alexandria, where nearly all the knowledge collected to that day was stored. The destruction of the library in war and as a result of the rise of Christianity, which viewed much of the contents of the library as heretical, may have set science and civilization back by several centuries.

In the New World, writing was invented in Mesoamerica independently of writing systems developed earlier in Egypt, Mesopotamia, and China,

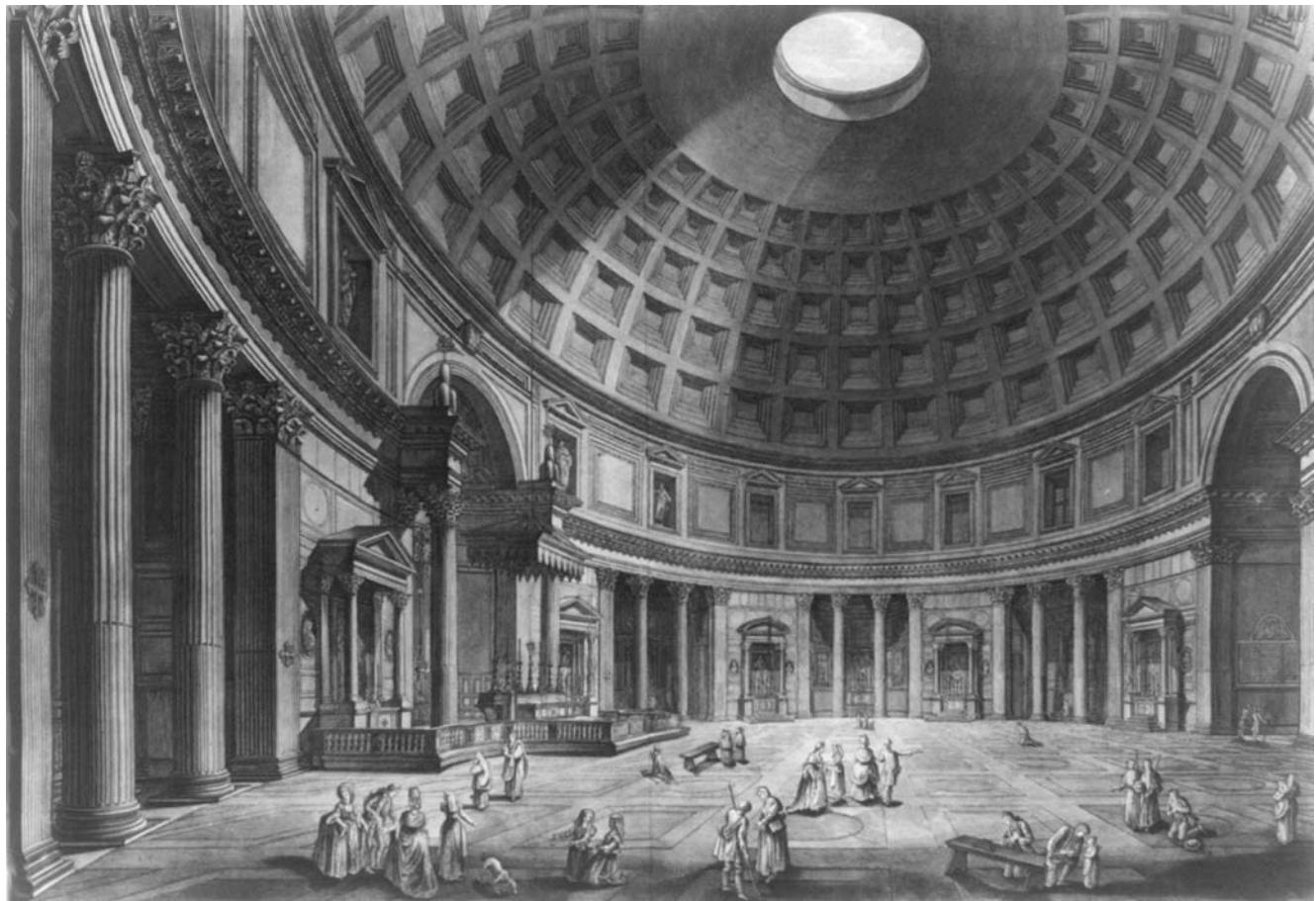
although civilizations in South America prospered without ever using this concept.

By the time of the early Ionian philosophers, maps purporting to show the entire Earth were being made, while charts of some sort for mariners must have existed even earlier. However, none have survived, probably because they were kept as state or commercial secrets. Latitude, longitude, and map grids were all invented, the first two by sailors.

CONSTRUCTION Much of the construction of this period was more practical than the tombs and temples of prior centuries. Canals and tunnels were built to bring water where it was needed. Roman engineers built famed aqueducts. Many Roman structures employed the arch, a versatile method of enclosing an open space that to a great degree held itself together with the force of gravity and which, when rotated, became the dome.

Temples were built, often featuring many columns, as in the Parthenon at Athens. Roman temples were more apt to have arches and domes, becoming the model for early Christian churches. Some of the structures built during this period have continued in use until today, although often repaired — rather like the ax that lasted 50 years and only needed two new heads and seven new handles during that time. Others, though not in use, still stand.

EARTH SCIENCE The beginning of earth science occurred in two ways. Various philosophers explained the presence of stone replicas of shells of sea creatures at the tops of mountains, correctly recognizing that such shells would have formed in the distant past and then turned to stone. Large fossil bones, probably of dinosaurs, were found. Some of the creatures depicted on Greek vases and identified as mythical beasts were apparently based on these fossils.



THE PANTHEON Roman engineers rotated an arch about its vertical axis to come up with the dome. One of their most remarkable domes, on the Pantheon, still stands in Rome today, where it has always been a major tourist attraction. The hole in the dome is for gods to enter and leave.

The other region of activity was in explanations of volcanoes and earthquakes, which began in myth and included such theories as Aristotle's notion that waves of the sea pushed air into underground chambers where it fed coal fires. The first realistic reports of volcanic activity were made in describing the eruption of Vesuvius in 79 CE.

ENERGY For the first time, power from a source other than animal muscles became important as various types of water wheel were constructed. The invention of gears was a prerequisite to making such wheels practical for oper-

ating mills of various kinds. Gears not only changed the direction of rotation from horizontal to vertical (or vice versa) but also changed speeds and forces as needed.

FOOD & AGRICULTURE Harvesting improvements for this period came last, with the first known harvesting machinery not used until the Roman Empire. Storage was promoted by turning grain into beer, wine, and even distilled spirits, although salting, drying, and pickling were also available and in wide use. Extraction of liquids from foods (such as oil from olives) was first handled by the bag press, but 1500

years later the Greeks invented the more efficient beam press.

MATERIALS In the West, writers turned from papyrus and clay to parchment (made from treated animal skins), while in the East paper was invented. The Romans introduced the widespread use of concrete in building structures. Glass windows began to adorn Roman buildings.

MATHEMATICS Both Pythagoras and Plato ranked mathematics as central to all knowledge, although Pythagoras emphasized number and Plato geometry. Greek geometry culminated with

the Alexandrian mathematician Euclid. His *Elements*, a coherent mathematical construction in which a large number of propositions are derived from a small number of postulates, formed the basis for teaching geometry well into the 20th century. Concepts that we now would recognize as parts of algebra or even calculus were placed into a geometric context and solved by the rules of geometry.

MEDICINE & HEALTH Many of the Greek philosophers, including Anaxagoras, Empedocles, Democritus, and Philolaus were physicians or were interested in medicine. Hippocrates of Cos and his followers became the best known for a more scientific approach to medicine and for their explanation of health and disease by the balance of “humors.” This theory remained unchallenged for many centuries and hampered the understanding of the role of pathogens. When Greek medical teaching spread to Rome, Galen became the best known physician, and his theories dominated medicine for the next 1300 years.

Anatomy suffered from many misconceptions. It was easy to see that the larger veins and arteries are tubes that can carry some sort of fluid through the body, so it was assumed that the nerves are also fluid-carrying tubes. When examining dead persons or animals, the arteries are no longer pumping blood, so a common misconception was that they contained air (air clearly was taken into the lungs). From there air could be carried by pulmonary arteries to the heart and from there pumped throughout the body (not really so far off in terms of how oxygen is distributed). Although it was clear that both the brain and heart are vital organs (necessary for life), the common medical opinion of Antiquity was that thought arises in the heart, making the role of the brain hard to understand.

An entirely different tradition of medicine started in India, focusing ini-

tially on surgical operations on the exterior of the body, including cataracts in the eyes.

PHYSICS Aristotle's views on physics, which were often incorrect, were lost for most of this period, but greatly affected ideas in the Middle Ages after they were recovered from Arab sources. His opposition to atomism was effective in Antiquity, however. He also solidified such concepts as the elements of earth, air, fire, and water.

Archimedes is classed among the first-rank mathematicians in history, but is better known for his advances in mathematical physics. He discovered the mathematical laws of levers and pulleys, and showed that a body immersed in a fluid would displace its own mass, a law known as the Principle of Archimedes.

TOOLS Because society in Antiquity was based on slavery, little incentive existed to apply science to technology, and most inventions were aimed at entertainment. Heron of Alexandria designed a series of automata and model steam engines, but used his devices for such tasks as opening temple doors at sunrise. Archimedes is famous for his Archimedean screw, a device for raising water in irrigation systems, and for his war engines used in defense of Syracuse. But the most practical Greek invention was the beam press, used mainly for extracting olive oil from olives. Hellenistic engineers built some remarkable canals and tunnels.

A modern carpenter or mason would recognize nearly all the tools from the Roman Empire, although a few would be different and, of course, many would be missing. A display of tools from a Roman workshop includes familiar hammers, hatchets, chisels, saws, awls, and pliers (pincers). The unfamiliar tool that looks somewhat like tongs or a geometer's compass is called a pair of dividers. Dividers were

used for measurement in place of today's rules of various types, all of which depend on what is essentially printing technology, not developed in the West until the 15th century.

Notably missing, in addition to rules, are the screwdriver and an array of wrenches, since the machine tools for cutting good screws and bolts were not invented until the start of the Industrial Revolution.

Since this period precedes the invention of gunpowder, the tools of war were quite different from those of today. The catapult was the first “weapon of mass destruction.”

TRANSPORTATION From early Greek times, transportation and trade were important, especially trade with Egypt. Canals and roads were built to shorten passages over narrow strips of land, such as the Isthmus of Corinth, although the Chinese also used canals to improve trade to parts of the interior of the Asian continent. Long-distance trade between the Roman Empire and China began along the Silk Road, not a road at all, but a series of cultures in contact, each of which carried goods for part of the way between Rome and China.

Greek and Hellenistic shipbuilders gradually extended their art throughout the period. This was a period when bigger and bigger warships were built, although all relied on rowers to maneuver and rams to sink their opponents.

Among the Roman structures that have had a lasting effect are the roads, built largely as routes for Roman infantry. The Roman highway engineers favored straight paths as the shortest distance; since the roads were largely intended for foot soldiers, they followed grades steeper than one would want for vehicles. Some Roman roads had grades as steep as 20 percent. A Roman highway was built to last, using four or five layers of sand, mortar, gravel, and concrete, topped with

hard rock set in more concrete. The result was more than 1 m (about 4 ft) thick and 2 or 3 m (up to 20 ft) wide. Since the road was often harder than

the surrounding soil, the roadbed of Roman roads tended to erode less and to become a long ridge across the land.

The Chinese began development of the magnetic compass, although it required centuries for it to be applied to navigation instead of divination.

CHRONICLE

600 BCE

■ Archaeology

Massalia (Marseilles, France) is founded by the Phoenicians. *See also* 700 BCE ARCH.

Babylon under the Chaldean king Nebuchadnezzar II [b. 630 BCE, d. 562 BCE] becomes the largest city on Earth with an area of 10,000 hectares (25,000 acres). *See also* 1000 BCE COMM; 539 BCE ARCH.

■ Construction

The Chaldean king Nabopolassar [ruled 626–605 BCE] builds the oldest stone bridge over a major river for which there is a record. Spanning the Euphrates, it is a drawbridge 116 m (380 ft) long that rests on seven pillars of stone, brick, and wood, with a wooden frame that has a section drawn up at night to keep people from crossing it. *See also* 512 BCE CONS.

■ Food & agriculture

The Chinese develop the art of fumigating houses to rid them of pests. *See also* 100 CE FOOD.

♦ Materials

Greek potters make several improvements. The potter's wheel is enlarged and made heavier, so that it acts as a fly-wheel. Pottery is shaved on the wheel after the pot has dried to give a finer surface. Kilns

are improved. An elaborate sequence of firing at specific temperatures and with various masks produces the characteristic black-and-red ware of the time. *See also* 700 BCE TOOL.

Greek sculptors begin to use marble from the islands of Paros and Naxos in carving statues. *See also* 450 BCE MATR.

Σ Mathematics

The Chinese text *Arithmetic Classic of the Gnomon and the Circular Paths of Heaven*, written about this time, contains the first known proof of a version of the Pythagorean theorem. *See also* 1200 BCE MATH.

♥ Medicine & health

Indian physician Susruta may have lived about this time, although some Indian scholars think he lived 400 years earlier. Some Western scholars say he was born c. 380 CE and died c. 450 CE. Perhaps several physicians shared a traditional name. Susruta performs the first cataract operations and plastic surgery. His writings describe diseases that come to be called malaria, tuberculosis, and diabetes. He mentions the use of hemp (*Cannabis*) in inducing anesthesia and is claimed to have observed the relationship of malaria to mosquitoes and of bubonic plague to rats. *See also* 1550 BCE MED; 500 BCE MED.

█ Tools

According to ancient sources, Anacharis the Scythian invents the anchor.

↗ Transportation

Periander, ruler of Corinth [627–585 BCE], has a road of 7.4 km (4.6 mi) built across the Isthmus of Corinth to transport ships across land on wheeled platforms that travel in limestone tracks. Periander orders this rail transport in lieu of digging a canal, which would have been too expensive. The ships, probably pulled by oxen, are mainly lightweight warships and perhaps small merchant ships. *See also* 2000 BCE TRAN.

Pharaoh Necho II [ruled 609–595 BCE] begins to dredge the Wadi Tumilat to connect the Nile with the Red Sea, but does not complete the canal (completed about 100 years later by the Persian King Darius or around 285 by Ptolemy II). *See also* 2000 BCE TRAN; 500 BCE TRAN.

Pharaoh Necho II abandons a plan to dig a canal from the Nile to the Red Sea in favor of sending a group of Phoenician ships around Africa from the Red Sea to the Mediterranean. According to Herodotus, the only source for this tale, the ships take three years, planting and harvesting crops along the way, but succeed in making the circumnavigation. Many today remain skeptical about the account. *See also* 800 BCE TRAN.

598 BCE

↗ Energy

In 598, the second year of the

reign of King Chao of Yen, (China), whale-oil lamps with asbestos wicks are used. However, this may have been in 308 BCE, as there were two King Chaos of Yen. *See also* 1100 BCE ENER; 250 BCE ENER.

589 BCE

■ Archaeology

The Babylonian Captivity of the Israelites begins when Nebuchadnezzar II of Babylon conquers Jerusalem and removes the inhabitants to Babylon. *See also* 600 BCE ARCH.

585 BCE

★ Astronomy

Thales of Miletus [b. Miletus (Turkey), c. 624 BCE, d. Miletus, c. 547 BCE] correctly predicts a solar eclipse that occurs on May 28, 585 BCE; the Medes and Lydians, taking the eclipse to be an ill omen, call off their war. *See also* 2136 BCE AST; 450 BCE AST.

Σ Mathematics

Thales of Miletus proves the first theorems of deductive geometry. Although there is some evidence of reasoning in Egyptian geometry, most geometry before Thales was based on general ideas obtained from measurement. The exact theorems proved by Thales are not known for sure, but he apparently uses logical arguments, although without

The first great explorers

The earliest explorers are barely remembered legends. Among legendary voyages is that of Jason and the Argonauts, now thought to record the first Greek expedition into the Black Sea, probably about 1000 BCE. Unknown Phoenician merchants opened up the western Mediterranean around the same time, establishing a farthest outpost at Gadir (Cadiz, Spain) on the Atlantic not far beyond the Pillars of Hercules (Strait of Gibraltar).

According to Herodotus, Pharaoh Necho sent an expedition from the Red Sea around 600 BCE that circumnavigated Africa clockwise over a period of three years. Few believe this, although Necho's ships probably did travel far down the east coast of Africa. Herodotus also tells of an early Persian expedition intended to circle Africa counterclockwise sometime between 485 and 464 BCE. These explorers traveled some way down the west coast of Africa before turning back.

About the same time as the second African expedition recorded by Herodotus, there was a Carthaginian effort to set up colonies, described by its commander, King Hanno. From his descriptions of the places encountered, it is apparent that he reached at least what is now Sierra Leone on the west coast of Africa, but perhaps traveled as far as Cameroon. The Carthaginian colonies he founded on the Atlantic coast were much farther north, however, along the shores of what are now Morocco and Western Sahara. Partly because of their Atlantic colonies, the Carthaginians controlled the Strait of Gibraltar for over a hundred years, making it almost impossible for any further exploration of the Atlantic by others from the Mediterranean regions.

But one daring sailor made it past the strait, probably about 310 BCE. From there Pytheas of Marseilles completed the greatest recorded voyage of exploration of ancient times, circumnavigating Great Britain and reaching Norway (or possibly Iceland). Not only did Pytheas travel about as far as Columbus did during his first voyage, but he returned with careful reports on all he had seen and with excellent navigational data. The primary purpose of the trip was probably to

locate the source of tin, which he found in Cornwall, but Pytheas had scientific goals in mind as well. Yet few at the time believed his accounts of frozen seas and other wonders.

Explorers also traveled along the coast of western Asia, but their names have been lost. These routes were pioneered by Indian and Arab navigators perhaps as early as 3000 BCE. The traders that followed the explorers eventually were displaced by Egyptians under the Ptolemies, starting with two voyages to India around 120 BCE by the explorer Eudoxus of Cyzicus.

By the reign of the Roman Emperor Augustus (27 BCE to 14 CE), there was regular trade between Rome and India, with hundreds of ships setting out from the Red Sea each year, many of them reaching India's Malabar coast and returning. Gradually the shipping routes were extended, with the farthest known extension being a trip (recorded by the Chinese) of a merchant to Vietnam in 226 CE. Chinese vessels then took the merchant to their emperor in Nanking. Travel went the other way as well. Chinese expeditions had traveled to Mesopotamian outposts of the Roman Empire as early as 97 CE.

Among the most amazing early explorers were the Polynesians. Their lack of a written language prevents our knowing the names of the men and women who pushed into the edge of the South Pacific as early as 32,000 BCE and settled most of it between 200 BCE and 1000 CE. Finding the tiny, remote islands of the Pacific was an amazing feat.

The Chinese also explored many islands, but their islands were larger and closer together — Japan, Taiwan, the Philippines. There is little evidence to support the most amazing claim of the Chinese, however. According to a legend dating from at least the sixth century CE, a Chinese junk captained by Xi and He around 2640 BCE sailed east from Japan for thousands of miles and found a continent. If true, it could only have been one of the Americas. One account has them traveling via the Bering Sea and penetrating as far south as Guatemala, while others have them reaching the Pacific Northwest and the coast of Ecuador. The best proof that something of this nature could occur are well-authenticated accounts of Japanese boats blown off course and landing in the Americas in the late 18th and early 19th centuries.

spelled-out axioms or postulates. *See also* 1650 BCE MATH; 430 BCE MATH.

* Physics

Thales of Miletus creates a system explaining matter in which water is the basis of all things. Matter appears to him to exist in three forms: mist, water, and earth. He considers mist and earth as forms of

water. In the field of astronomy, which he has learned from the Babylonians, Thales claims that the substance of stars is water. *See also* 530 BCE PHY.

560 BCE

■ Construction

Nebuchadnezzar of Babylon

builds a high dam that is roughly 25 km (16 mi) long, joining the Tigris to the Euphrates and creating a giant lake behind it. It is an earth-filled dam lined with fired brick using mastic (bitumen and sand) mortar. The primary purpose of the lake is to act as a giant moat on one side of Babylon for defensive purposes. *See also* 280 BCE TRAN.

550 BCE

■ Biology

Anaximander of Miletus [b. Miletus (Turkey), 610 BCE, d. Miletus c. 546 BCE], in *On Nature*, introduces the concept of evolution and speculates that animal life began in the oceans — ideas forgotten for centuries. *See also* 530 BCE EAR.

The first known date

The earliest history of humanity has no known date. After writing began to be used, people started dating events, but these were usually in relation to other events that we can no longer date. The long histories of Egyptian and Chinese dynasties, however, provide fairly good year dates for those cultures back to 3000 BCE.

The Mayans recorded specific day dates that go back in time tens of thousands of years. Since many of the events dated in their system occurred before the most optimistic early date for humans in North America, it is assumed that these very early dates are for mythical events that were invented much later. Very early Chinese dates also are thought to have been later inventions.

A strong candidate for the first real date in history — that is, the first specific day on which an event can be pinpointed as having occurred — is May 28, 585 BCE. The event was a battle between the Medes and the Lydians that was suddenly called off when an eclipse of the Sun frightened both armies. This eclipse, supposed to have been forecast correctly by Thales (although at best he would have had the year right, not the date), could only have been the one observable in the Middle East on May 28, 585. No other solar eclipse would have been visible in that region for many years on either side of 585.

An even earlier candidate for the first date, October 16, 1876 BCE, comes from Chinese astronomical records and is for a solar eclipse recorded in the reign of King Zhong Kong. It is the earliest date that records an astronomical event that we can say occurred at a particular time. However, it is not connected with any other event such as the war of the Medes and Lydians.

Communication

Anaximander draws up the first known map of the entire inhabited Earth — actually only the part known to the Ionians around this time. He puts the map on a cylinder to reflect the curvature of Earth. *See also* 500 BCE COMM.

Tools

According to tradition, Anaximander invents the first sundial. In fact, simple sundials existed earlier in Mesopotamia and Egypt, but probably

Anaximander invented a form of astrolabe or sundial that could be corrected for changes in the season. *See also* 1500 BCE TOOL.

540 BCE

Mathematics

There is a productive period in mathematics. Ionian philosophers follow Thales in developing deductive proofs, the Chinese introduce rod numerals, and the Indians develop a geometry based on

stretching ropes (similar to an earlier Egyptian practice). *See also* 300 BCE MATH.

530 BCE

Construction

Greek architect and engineer Eupalinus of Megara (Greece) [b. c. 570 BCE] builds an aqueduct and water-supply system for Megara, although he is much more famous for the water supply system he later builds on Samos. *See also* 522 BCE CONS.

Earth science

Greek philosopher Xeno-phanes [b. Colophon, Ionia (Turkey), c. 570 BCE, d. 480 BCE] speculates that since fossil seashells are found on tops of mountains, the surface of Earth must have risen and fallen in the past. *See also* 550 BCE BIO; 350 BCE EAR.

Physics

Greek philosopher Anaximenes of Miletus [b. Miletus (Turkey), c. 570 BCE, d. c. 500 BCE] suggests that air is the primary substance — it can be changed into other substances by thinning, forming fire; or thickening, forming wind, clouds, rain, hail, earth, and rock. He recognizes that the rainbow is a natural phenomenon rather than a divine one. *See also* 585 BCE PHY.

522 BCE

Construction

Architect and engineer Eupalinus of Megara constructs a 1.7 m high by 1.7 m wide (5.5 ft by 5.5 feet) tunnel 1006 m (3300 ft) long under 275-m-high (900-ft-high) Mount

Castro on the island of Samos (Greece) to supply water. The tunnel is built from both ends and the two parts miss by about 6 m (20 ft) horizontally and 1 m (3 ft) vertically (known from archaeological measurements made in the 1870s and 1880s). *See also* 530 BCE CONS.

520 BCE

Astronomy

Pythagoras of Samos [b. Samos (Greek Aegean island), c. 569 BCE, d. Metapontum (Italy) or Croton (Crotone, Italy), c. 480 BCE] recognizes that the morning and evening stars are the same heavenly body, the planet Venus. He proposes that the Sun, Moon, planets, and stars move in paths around Earth, which is suspended in space. *See also* 450 BCE AST.

Earth science

Pythagoras recognizes that Earth is a sphere. *See also* 550 BCE COMM.

Physics

Pythagoras discovers that musical harmony can be explained with number (for example, doubling the length of a plucked string produces a note one octave lower). *See also* 500 BCE CONS.

512 BCE

Construction

Darius I of Persia [b. Persia, c. 550 BCE, d. 486 BCE] has the Samian engineer Mandrokles build a floating pontoon bridge across the Bosphorus to let his army invade Macedonia. *See also* 490 BCE TRAN.

Mathematics and mysticism

Pythagoras was among the early Greek philosophers. He is said to have visited Thales and studied with Anaximander. He traveled to Egypt and Mesopotamia, learning the basics of philosophy, science, and mathematics. After returning to Samos and teaching there, he moved to Croton (Crotone, Italy). There he formed a secret society of men and women who shared their knowledge of science and mathematics. Today they are known as Pythagoreans. Credit for many discoveries attributed to Pythagoras probably belongs to other members of his secret society.

The society was both a mystical religion and one of the most productive schools of mathematics in history. A fundamental mystical belief of the Pythagorean society was that "all is number," which is to say that the entire universe can be explained in terms of numbers. The Pythagoreans had other mystical beliefs as well, such as an aversion to beans and a belief in the transmigration of souls (that is, that people's souls after death occupy the bodies of animals and vice versa).

But the principal ideas of the Pythagoreans that have been handed down concern numbers. The Pythagoreans assigned gender to numbers, saying that odd numbers are male and even numbers female. They also worked with figurate numbers, numbers that can be identified by a shape when dots are used. Square numbers of dots can be formed into squares, triangular numbers form dot triangles, and so forth.

Although the name Pythagoras is most closely associated with the Pythagorean theorem (the sum of the squares on the legs of a right triangle equals the square on the hypotenuse), this theorem was known to the Chinese and probably to the Babylonians before the time of Pythagoras.

When Pythagoreans talked about numbers, they meant the natural numbers, 1, 2, 3, and so forth. Fractions are simply ratios of natural numbers, so fractions posed no problem. But the Pythagoreans proved that objects in the real world cannot always be measured completely with natural numbers. For example, if the unit chosen to be one is the side of a square, the diagonal of the square cannot be measured exactly using that unit.

509 BCE

■ Archaeology

According to tradition, Rome succeeds in winning its independence from the Etruscans and becomes a republic. *See also* 753 BCE ARCH.

500 BCE

■ Biology

The Greek Pythagorean physician Alcmaeon of Croton [b. Croton (Crotone, Italy) c. 535 BCE], pursuing anatomical research, concludes that humans are fundamentally different from animals. *See also* 350 BCE BIO.

Navigator Hanno of Carthage [b. Tunisia, c. 530 BCE], after his voyage down the African coast, describes the gorilla.

■ Communication

Greek traveler and historian Hecataeus of Miletus (Turkey) [b. Miletus, c. 550 BCE, d. c.

476 BCE] develops a map of the world showing Europe and Asia as half disks surrounded by ocean. *See also* 550 BCE COMM; 380 BCE COMM.

■ Construction

Greek theaters begin to be constructed with the wave nature of sound in mind. Among other uses of acoustic principles, open vases are placed around the theaters as resonators to enhance sound levels. *See also* 520 BCE PHY.

Zapotecos near what is Oaxaca, Mexico, begin to erect stone pyramids, notably at Monte Albán, 500 m (1300 ft) above the surrounding countryside. *See also* 800 BCE CONS.

An early ceremonial center, known today as Kaminaljuyú, featuring several hundred earthen mounds and serving partly as a burial ground, is built by the Maya (near Guatemala City, Guatemala). It will be later (c. 300 CE to 600 CE) rebuilt along the lines of



MONTE ALBÁN The ancient capital of the Zapotec was among the first cities in North America, flourishing for about 250 years after its founding in southeastern Mexico.

Teotihuacán. *See also* 300 BCE MATH.

North American natives in what is now the Midwest and Southeast of the United States build giant earthen mounds that raise temples high and are also used as burial places. *See also* 800 BCE CONS.

■ Earth science

The Chinese recognize the water cycle, which is the path water takes from clouds to precipitation to rivers and the ocean and back to clouds

again. In the West, its existence is first demonstrated in the late 1600s by Edmond Halley. *See also* 585 BCE PHY; 350 BCE EAR.

■ Food & agriculture

Chinese farmers use practices, such as planting crops in rows, hoeing weeds, and applying manure, that will not be used in the West until the 18th century.

■ Materials

Steel is made in India. *See also* 400 CE MATR.

Ironworking is common throughout the area that today is Germany and Scandinavia. *See also* 700 BCE MATR; 450 BCE MATR.

Well before this time the Persians develop composite bows made from animal tendons and horn instead of from wood. Such bows do not deteriorate in hot weather and can be left strung for long periods of time without losing elasticity. *See also* 3500 BCE TOOL.

♥ Medicine & health

Alcmaeon of Croton is the first person to dissect human cadavers for scientific purposes. He notes the optic nerve and the eustachian tubes, differentiates veins from arteries, and recognizes the brain as the seat of the intellect. *See also* 600 BCE MED.

I Tools

Romans develop the first safety pins, but the idea is lost with the fall of the Roman Empire and not revived until re-invented in 19th-century America. *See also* 1849 TOOL.

The early Iron Age, from 1100 to 500 BCE, sees the invention of lathes, saws, pegs, shears, scythes, iron axes, picks, and shovels. Particularly good evidence for the presence of the lathe is a bas-relief of Darius I at Persepolis showing him on a throne that has legs and rungs that have been clearly turned on a lathe.

Stonemasons' tools, mostly punches and chisels, are being made from iron, as are the saws and chisels of woodworkers.

→ Transportation

Darius, the Persian king, has the canal of Pharaoh Necho from the Nile to the Red Sea completed, effectively linking the Mediterranean with the Indian Ocean. The canal is 145 km (90 mi) long and 45 m (150 ft) wide. Eventually, like most ancient canals, it gradually fills and falls into disuse, although it is reopened about 285 BCE by Ptolemy II. Some authorities say that Darius stopped short of making the actual connection for fear that the higher level Red Sea would cause the Mediterra-

nean to rise. *See also* 600 BCE TRAN; 280 BCE TRAN.

A picture on the wall of an Etruscan tomb is the earliest known depiction of a two-masted sailing vessel. The foremast carries a smaller sail than the mainmast and slants forward over the bows. *See also* 3000 BCE TRAN; 1 CE TRAN.

490 BCE

❖ Materials

In September, Greeks win the battle of Marathon largely because Persian arrows fail to penetrate Greek armor. Ten thousand Greeks from a combination of city-states defeat 20,000 Persians loyal to Darius. *See also* 1346 CE MATR.

→ Transportation

The astronomer Harpalos builds a floating bridge across the Bosphorus for the army of Xerxes of Persia using 674 ships as its pontoons, all laced together with flaxen cables. The army successfully marches across the strait, but is defeated by the Greeks. *See also* 512 BCE CONS.

475 BCE

★ Astronomy

Greek philosopher Parmenides [b. Elea (Italy) c. 515 BCE, d. c. 450 BCE] explains the phases of the Moon in terms of its illumination being reflected sunlight. He holds that change is illusory, since being is one, and nothing can be created or destroyed. *See also* 28,000 BCE AST.

❖ Physics

Greek philosopher Heraclitus [b. Ephesus (Turkey), c. 540 BCE, d. c. 475 BCE] teaches that

change is the essence of all being. *See also* 530 BCE PHY; 450 BCE PHY.

470 BCE

★ Astronomy

Greek philosopher Anaxagoras of Clazomenae [b. Clazomenae, Ionia (Turkey), c. 500 BCE, d. Lampsacus (Turkey), c. 428 BCE] claims that heavenly bodies are made of the same stuff as Earth and that the Sun is a large, hot, glowing rock. He explains eclipses of the Sun and Moon in terms of Earth or the Moon casting a shadow. *See also* 3000 BCE AST.

❖ Physics

Anaxagoras postulates that a large number of "seeds" make up the properties of all materials. Creation came when Earth expelled all the heavenly bodies into space. *See also* 530 BCE PHY.

450 BCE

★ Astronomy

Philosopher Empedocles [b. Akragas, Sicily, c. 492 BCE, d. Mount Etna, c. 432 BCE] proposes that eclipses of the Sun are caused by the Moon coming between Earth and the Sun. *See also* 520 BCE AST.

Greek philosopher Oenopides [b. Chios, Greece, c. 490 BCE, d. c. 420 BCE] calculates the angle that Earth is tipped with respect to the plane of its orbit (an angle apparent to anyone who regularly watches the stars — it is not necessary to assume that Earth travels in a path around the Sun). His value of 24° is only half a degree from the presently accepted value of 23.5° and will be used until

Eratosthenes refines it to the more precise value.

❖ Materials

An ironworking industry develops in Great Britain. *See also* 500 BCE MATR.

Although early Greek temples were constructed of sun-baked brick and wood, marble eventually replaces these materials, although at first the marble is treated in much the same way as the earlier brick — stuccoed over and painted. About this time an excellent source of marble is found on Mount Pentelicus, a short distance north of Athens, enabling Greek builders to construct the famous white marble buildings and statues of the Acropolis. Because such marble can be cut in beams up to 4.5 m (15 ft) long, Greek architects do not need to utilize arches, corbels, or domes on roofs, sticking mostly with post and lintel construction.

Greek historian Herodotus of Halicarnassus (Turkey) [b. 484 BCE, d. c. 425 BCE] explores the Middle East, Babylon, and Persia about this time and gives the first description of cotton, which he finds in India. *See also* 3000 BCE FOOD.

Σ Mathematics

The Greeks develop a method of writing numbers based on letters of the alphabet. *See also* 3100 BCE MATH.

♥ Medicine & health

Empedocles recognizes that the heart is the center of the system of blood vessels, but wrongly concludes that this organ must also be the seat of the emotions, a notion that was accepted by many later Greek writers and that has persisted in folk tradition ever since. *See also* 275 BCE MED.

The elements

The concept of an element, or irreducible part of a substance, is of Greek origin, although the Greeks did not think of elements as we do today. The term *element* was coined by Plato, but the idea existed before him. Empedocles believed that all matter was made up of four primary substances, or elements: earth, air, fire, and water. All the appearances of matter could be explained by the commingling and separation of these elements under two influences that acted upon them: love, comparable to the physicist's force of attraction; and strife, comparable to repulsion.

Plato adopted Empedocles' theory of elements. Because Plato believed that geometry employs the best method for thinking about nature, he provided the elements with exact mathematical form. The smallest part (or atom) of fire was in

the shape of a tetrahedron, air of an octahedron, water of an icosahedron, and earth of a cube.

Aristotle also adopted the concept of four elements. But contrary to Empedocles' theory, in which the elements are immutable and compounds differ only in their composition, the elements of Aristotle undergo changes when they combine. Aristotle believed that besides physical extension, elements have qualities that are based on how we experience matter: hot, cold, dry, and moist. He saw each element as endowed with two of the four qualities, so earth was dry and cold, water moist and cold, air moist and hot, and fire hot and dry. One element could change into another by changing one or two of its qualities. For example, earth could change into water by changing from dryness to moistness. He also introduced a fifth element, or quintessence, that existed only in the heavens. Quintessence was viewed as unchangeable, unlike the easily changed elements of direct human experience.

* Physics

Greek philosopher Protagoras [b. Abdera (Spain), c. 490 BCE, d. c. 420 BCE] believes that sense perceptions are all that exist, so that reality may be different from one person to another. *See also* 440 BCE PHY.

Empedocles of Akragas introduces a system in which fire, air, earth, and water are the elemental substances that can undergo change through the action of two opposing forces, love and strife. *See also* 475 BCE PHY.

Greek philosopher Leucippus of Miletus (Turkey) [b. c. 480 BCE, d. c. 425 BCE] introduces the first idea of the atom, an indivisible unit of matter. *See also* 430 BCE PHY.

447 BCE

Construction

Pericles [b. Athens, Greece, c. 495 BCE, d. Athens, 429 BCE] orders construction of the Parthenon to commemorate the triumph of the Greek

army over the Persians at the battle of Plataea. *See also* 438 BCE CONS.

440 BCE

* Physics

Greek philosopher Gorgias [b. Leontini, Sicily, 483 BCE, d. 376 BCE] flourishes. He is a nihilist who believes nothing exists. If it did exist, he maintains, we could not know it; and if we knew it, we could not tell anyone else about it. *See also* 450 BCE PHY.

438 BCE

Construction

Greek sculptor Phidias [b. Attica, Greece, c. 500 BCE, d. c. 432 BCE], working with architects Actinus and Callicrates, completes the Parthenon in Athens to the extent that it can be used for the dedication of Phidias' gold-and-ivory statue of Athena, although further construction continues. *See also* 432 BCE CONS.

432 BCE

* Astronomy

Meton of Athens [b. Athens, c. 440 BCE] develops what we now call the Metonic cycle, the (approximately) 19-year period in which the motions of the Sun and Moon seem to come together from our vantage point on Earth. This period can be used to predict eclipses and forms the basis of the Greek and Jewish calendars. *See also* 475 BCE AST.

Construction

Construction of the Parthenon is completed shortly before the death of Pericles. *See also* 438 BCE CONS; 1687 CE CONS.

Earth science

Empedocles, according to legend, jumps into a volcano's crater after failing to be taken into the heavens to become a god, which he had predicted would happen. *See also* 79 CE EAR.

431 BCE

Σ Mathematics

When the Athenians, suffering a plague, appeal to the oracle at Delos, they are told that they need to double the cubical altar of Apollo to rid them of the plague. Their failure to do so leads to one of the three classic problems, the duplication of the cube.

♥ Medicine & health

Greek historian Thucydides [b. Athens, Greece, c. 471 BCE, d. c. 400 BCE] writes his account of the Peloponnesian War between Athens and Sparta, in the course of which he describes the plague of Athens in great detail. It is a mysterious, fatal disease that scientists today have failed to identify. Thucydides observes that "individuals who recover from the plague do not contract it again." *See also* 1345 CE MED.



THE PARTHENON Although much of the sculpture was carried off to England, and the stripped building also suffered serious damage from a 19th-century explosion, the ancient Greek temple remains an icon of architecture even in its ruined state — partially restored since this photograph, however.

430 BCE

Communication

An optical telegraph using torches to signal from hilltop to hilltop operates in Greece. It uses combinations of 5 torches to indicate each letter of the Greek alphabet. *See also* 1792 CE COMM.

Earth science

Democritus of Abdera [b. Abdera, Thrace, c. 470 BCE, d. c. 380 BCE] is reputed to be able to predict the weather. *See also* 330 BCE EAR.

Mathematics

Hippocrates of Chios [b. Chios (Greek island), c. 470 BCE, d. c. 410 BCE] writes his *Elements of Geometry*, which predates Euclid's more famous *Elements* by more than a century. Since the work has been lost, it is not clear what it contained. However, his most famous discovery is the method of squaring a figure with two sides that are each segments of circles. The figure is called the lune because of its resemblance to the crescent Moon. He is also credited with introducing indirect proof, a

method in which the opposite of what is to be proved is shown to be impossible. *See also* 585 BCE MATH; 300 BCE MATH.

Physics

Democritus of Abdera expands the concept, introduced by his teacher Leucippus, of the atom as an indivisible body and shows how every form of matter can be explained by his version of the atom. *See also* 450 BCE PHY.

420 BCE

Mathematics

Hippias of Elis [b. Elis, Greece, c. 460 BCE, d. c. 400 BCE] discovers the curve called the quadratrix, which can be used to trisect an angle (and to square a circle, although Hippias probably did not know this). The quadratrix is the first curve known that is not a part of a straight line (mathematicians call straight lines “curves”) or a circle and that cannot be constructed with straightedge and compass. *See also* 431 BCE MATH; 240 BCE MATH.

Early atomists

The concept of the atom as the smallest, indivisible entity is one of the oldest ideas of science. It has its origin in a philosophical problem the Greeks tried to solve. Heraclitus believed that the basic nature of all things is *change*. His famous paradox is that one cannot step into the same river twice because the water has moved on between the steps. Parmenides, however, disagreed with Heraclitus and stated that reality is unchangeable and that change is a mere illusion. His pupil Zeno illustrated this by arguing that an arrow cannot be moving because at any one instance it occupies a particular spot.

Democritus (and probably Leucippus, thought to be the father of atomic theory, but of whom little is known) tried to reconcile these ideas. Democritus argued that it is impossible to keep dividing entities into smaller and smaller parts. Change is part of reality, but takes place within the philosophical framework of Parmenides. Change for Democritus was the local motions of parts that in themselves were unchangeable and invisible: the atoms. Atoms themselves must have a place to move. To Democritus atoms comprise all being but do not fill up all space; everything else is void — what we today would call empty space or the vacuum.

Democritus tried to explain the different forms in which matter exists, and some of his ideas seem quite modern, although coming from a perspective that does not really resemble today's ideas about atoms. For example, although each atom is too small to be observed, material objects appear because we can observe large groups of atoms assembled in a single place. Democritus thought that substances differ from each other because of the shapes, positions, and grouping of the constituent atoms. In solid bodies the atoms stick together. In fluids — liquids and gases — atoms do not stick together, they rebound from one another in random directions. Denser bodies are made up of larger, but still invisible, atoms. In his theory, there is no limit to the size of an atom; he believed that atoms as big as a world could exist somewhere.

Atomism had few followers before the 17th century. Eublides attacked the theory with the paradox of the heap — there is no such thing as a heap of sand because one grain is not a heap and if you do not have a heap of sand, adding another grain will not produce a heap. The analogy is with the creation of observables by combining unobservables. Aristotle and Plato rejected the theories of Democritus, with Aristotle unable to accept the void.

410 BCE

★ Astronomy

Horoscopes setting out the positions of the planets at the time of an individual's birth are available in Chaldea.

Σ Mathematics

A follower of Pythagoras, probably before this time, discovers that some lengths cannot be measured with the same unit used to measure other lengths; for example, the diagonal of a square is incommensurable with its sides.

↗ Transportation

Carthaginians begin to build quadriremes, ships with four banks of rowers, for their navy with the intention of invading Syracuse. Diodorus Siculus, however, says that workers

hired by Dionysius the Elder of Syracuse [b. Syracuse, c. 430 BCE, d. 367 BCE] were the "first to think of construction of such ships" in 399 BCE. See also 399 BCE TRAN.

400 BCE

❖ Ecology & the environment

Hippocrates of Cos [b. Cos (Kos, Turkey), 460 BCE, d. Thessaly, c. 370 BCE] observes that a man involved in lead mining developed abdominal cramps. He recommends boiling water to remove pollutants.

↗ Energy

The Chinese in Sichuan start using petroleum and natural gas for cooking and lighting, piping gas in bamboo tubes from regions where it arises

from the earth and taking petroleum from natural seeps. See also 100 BCE ENER.

♥ Medicine & health

Hippocrates founds a school of medicine on the Aegean island of Cos. His followers develop the Hippocratic Oath, still taken by physicians, and encourages separation of medicine from religion. This earns him the sobriquet "the Father of Medicine." Inspired by Empedocles' theory of four elements, the Hippocratic medical tradition eventually develops the theory of the four humors in the human body — blood, phlegm, yellow bile, and black bile. An imbalance in the humors is thought to be the cause of illness.

Hippocrates writes the first clinical description of diphtheria.

I Tools

Locks operated with keys are invented in Sparta (Greece).

↗ Transportation

Semilegends Chinese artisan Lu Pan produces the first known kite. See also 1232 COMM.

399 BCE

↗ Transportation

Dionysius the Elder of Syracuse introduces the quinquereme (a ship with five banks of rowers) to his navy, which already includes quadriremes. As a result, Syracuse becomes a major naval power, sweeping the Tyrrhenian and Adriatic seas free of pirates. Athens and other Hellenic cities soon begin adding the two new types of ship to

Three classic problems

About 430 BCE a great plague struck Athens. The Athenians appealed to the oracle at Delos to provide a remedy. The oracle said that Apollo was angry because his cubical altar was too small. If it were doubled, the plague would end. The Athenians had a new altar built that was twice the original in length, breadth, and height. The plague became worse. Consulting the oracle again, the Athenians learned that Apollo was angrier than ever. The god wanted the volume of the cube doubled, and the Athenians had octupled it. The plague went on until 423. The problem of doubling the cube went on until the 19th century.

Or so the story goes. There are other stories (but not as good) about how the Delian problem, as doubling the cube came to be known, arose. Whatever its origin, the Delian problem together with the problems of squaring the circle and trisecting the angle became the three classic unsolved problems of Greek mathematics.

It is essential to understand that the method of solution for the classic problems was restricted. A solution would count only if it were accomplished by a geometric construction using an unmarked straightedge and a compass that collapsed when lifted from the paper. Tradition has it that Plato was responsible for setting this requirement. Although a great many other problems were easily solved under the restriction, the three classics stubbornly refused to yield.

It is likely that the first classic problem was squaring the circle. It is thought that Anaxagoras worked on solving it, about 450 BCE, while he was in prison for having claimed that the Sun is a giant red-hot stone and that the Moon shines by reflected light. The problem specifically is to construct a square that has the same area as a given circle.

The trisection problem arose around the same time. In that case, the problem was to find an angle whose angle measure is exactly one-third that of a given arbitrary angle. Trisection appears deceptively simple since among the easiest constructions are the trisection of a line and the bisection of an angle. Like the other classic problems, it stumped the ancient Greeks, but not completely.

The apparent progress toward squaring the circle by Hippocrates of Chios (not to be confused with Hippocrates of Cos, the father of medicine) around 430 probably encour-

aged other mathematicians to continue. Hippocrates succeeded in squaring a region bounded by two arcs of circles. This figure looks like the crescent Moon and is therefore called the lune. Hippocrates made the first successful attempt to convert an area bounded by curves to one bounded by straight lines.

A number of mathematicians decided to stretch the rules and solve the problem ignoring Plato's restriction. Hippas of Elis is supposed to have found two different ways to square the circle, both explicitly rejected by Plato (according to Plutarch). One of the methods attributed to Hippas, based on the first curve other than a line or circle that was well defined and constructible (the quadratrix), was used to square the circle at a later date. Similarly, while trying to solve the Delian problem, Menaechmus seems to have discovered the conic sections — the ellipse, the parabola, and the hyperbola. Use of these curves enabled him to duplicate the cube. Archimedes solved two of the classic problems, trisection of the angle and squaring the circle, with his famous Archimedean spiral (a curve invented by Conon of Alexandria). Archimedes also discovered that all that is needed to trisect an angle is a marked straightedge instead of an unmarked one. In a related development, Archimedes managed to square a region bounded by a parabola and a line.

Around 320 CE, Pappus declared that it was impossible to solve any of the classic problems under the Platonic restriction, although he did not offer a proof of this assertion. Nevertheless, many continued to work on the classic problems in the traditional manner. Finally, the 19th century produced the definitive "solutions" to all three problems. Each problem was shown to be incapable of any solution that met the Platonic requirement, just as Pappus had stated. In 1837, Pierre Wantzel supplied a rigorous proof that an angle cannot be trisected with an unmarked straightedge and collapsing compass. In 1882, Ferdinand Lindemann showed that π , the ratio of the circumference of a circle to its diameter, is a transcendental number, implying that the circle cannot be squared. As for the Delian problem, it had been shown even earlier that it required construction of a line whose length is the cube root of two. With a straightedge and compass, it is only possible to construct square roots.

Although it is clear to mathematicians that the solution of the classic problems under Plato's restriction is impossible, amateurs continue to offer their "proofs" of success.

their own navies. By 325 BCE Athens has 43 quadriremes and 7 quinqueremes along with its main fleet of 360 triremes. *See also* 410 BCE TRAN; 315 BCE TRAN.

397 BCE

I Tools

Double-armed catapults operating on the principle of torsion are introduced by engi-

neers working for Dionysius the Elder of Syracuse. These devices, which use hair ropes to hold potential energy, are used to propel darts at the enemy. *See also* 332 BCE TOOL.

390 BCE

S Mathematics

Platonist Theaetetus [b. Athens, Greece, c. 415 BCE, d. Athens, 369 BCE] extends the

Pythagoreans' work on incommensurables — what modern mathematicians recognize as irrational numbers. He treats not only square roots but also other types of geometric incommensurables and classifies them. His work (and that of Eudoxus) is thought to be the basis of Book X of Euclid's *Elements*. See also 410 BCE MATH; 380 BCE MATH.

I Tools

Greek mathematician Archytas [b. Tarentum (Italy), c. 420 BCE, d. c. 350 BCE] builds a series of toys, among them a mechanical pigeon propelled by a steam jet. He is also credited by some with the invention of the pulley. See also 700 BCE TOOL.



Plato

[b. Athens, Greece, 427 BCE, d. Athens, 347 BCE]

Plato had a career in the military and politics and traveled widely before (and even after) starting his famous school, the Academy, in Athens. Many of his views are known from imagined dialogues that feature his friend Socrates [b. Athens, Greece, 469 BCE, d. Athens, 399 BCE]. Plato, although not a mathematician himself, viewed geometry as the basis of the study of any science. This fit with his philosophical concept of ideal forms, such as a perfectly one-dimensional line that drawn lines imitate. He also emphasized proof in mathematics. His views were generally followed by Greek mathematicians throughout Antiquity.

387 BCE

★ Physics

The Greek philosopher Plato founds his school, the Academy, at Athens and begins his trilogy, *Timaeus*, *Critias*, and *Hemocrates*, finishing only *Timaeus*, in which he expounds his theory of four elements — earth, water, air, and fire — and hints at a fifth element, the ether. See also 450 BCE PHY.

I Tools

Plato is said to build an “alarm clock” to wake up his students. According to one account, it is a clepsydra that consists of a vessel slowly filling with water and in which floats a bowl with lead balls. When the bowl reaches the rim of the vessel, it topples over and the lead balls fall on a copper plate. Another reconstruction has Plato using two jars and a siphon. Water slowly empties through the night until it reaches the siphon, whereupon it swiftly is transported via the siphon to the other jar. Water rising in the other jar forces air through a whistle, sounding the alarm. See also 1380 BCE TOOL.

380 BCE

★ Astronomy

Eudoxus of Cnidus [b. Cnidus (Turkey) c. 408 BCE, d. Cnidus, c. 355 BCE] develops the first version of a theoretical explanation of the motions of the planets, probably in response to a problem posed by Plato. He assigns each planet three or four spheres, each of which is centered on Earth. As the planet moves on the innermost sphere, that sphere is also carried by the next sphere out, which in turn is carried

by the third sphere (and that by a fourth for each planet, with three needed only for the Sun and Moon). Each sphere moves uniformly on its own axis of rotation. By carefully choosing the axes and speeds for each of 27 spheres, the system describes the motions of all the heavenly bodies up to the limits of observations at that time. See also 470 BCE AST; 350 BCE AST.

↳ Communication

Eudoxus improves on the primitive map of the Earth of Hecataeus. See also 500 BCE COMM; 300 BCE EAR.

Σ Mathematics

Eudoxus introduces the idea of magnitude, the geometric concept corresponding to the modern definition of real number. Magnitudes can be contrasted with numbers, which to Greeks were viewed as discrete, jumping directly from one value to another with nothing in between (as, for example, there is no counting number between 1 and 2). Eudoxus' treatment, based on the concepts of ratio and proportion, was the first mathematical treatment of any kind to introduce specific axioms.

Much of Euclid's Book X of the *Elements* is based on Eudoxus, although Euclid assumes without mentioning it at least one axiom that Eudoxus is thought to have stated explicitly, as reported by Archimedes. See also 390 BCE MATH.

Eudoxus develops the method of calculating the area or volume of a geometric figure by exhaustion, now seen as the first use of the principles that were to become the integral calculus in the 17th century. See also 250 BCE MATH.



Aristotle

[b. Stagira, Macedonia, Greece, 384 BCE, d. Chalcis, Euboea, Greece, 322 BCE]

Influenced by his father, the physician Nicomachus, Aristotle developed an early interest in science. As a student of Plato he formed a love of philosophy and logic. He then became the tutor to Alexander of Macedon (later Alexander the Great). After Alexander became king, Aristotle returned to Athens, where he founded his own school, known formally as the Lyceum and less formally as the Peripatetic (“walking around”) school, because students followed their teacher as he walked in the garden. Aristotle is considered the father of biology. Alexander the Great became his patron, funding his work and arranging for Aristotle to receive samples of plants and animals from all corners of the Alexandrian empire. Ancient scholars attributed as many as 400 treatises to Aristotle, encompassing all knowledge in Antiquity about the universe. About 30 have survived and these are thought to have been compiled by his students.

350 BCE

★ Astronomy

Aristotle adds 29 more spheres to the system of Eudoxus, producing a complex theory involving 56 spheres that is largely rejected by later Greek astronomers (although revived in medieval times). His spheres are all in contact so that one moves the others, with the prime mover being either the sphere of stars or an

unseen mover behind that sphere. *See also* 380 BCE AST.

Aristotle explains solar and lunar eclipses, and argues that the Sun, Moon, and Earth are all spherical. He also studies comets, but fails to recognize them as heavenly bodies. *See also* 432 BCE AST.

Greek astronomer Heracleides [b. Heraclea Pontus (Turkey), c. 388 BCE, d. Athens, 315 BCE] becomes the first person known to suggest that Earth rotates and that Venus and Mercury may orbit the Sun. *See also* 470 BCE AST; 270 BCE AST.

Biology

Aristotle dissects plants and animals and recognizes the need for classification, categorizing more than 500 species. He also studies the development of the embryo by observing unhatched birds. *See also* 500 BCE BIO.

Communication

Aristotle describes image projection. Having observed that a partial eclipse of the Sun projects the Sun's image through small spaces between leaves of a tree, he experiments with using what amount to pinholes to project bright images onto screens. The same idea is behind the camera obscura and the pin-hole camera.

Construction

Celtic chiefs begin building Maiden Castle in south Dorset, England, one of the great fortified earthworks of Neolithic Britain.

Earth science

Aristotle proposes that fossils are accidental natural formations, a theory that remains

popular for many centuries. He correctly describes the water cycle, but also thinks that earthquakes are caused by winds, thunder is caused by collisions between clouds, and lightning is the fire produced in the collision. *See also* 530 BCE EAR.

Mathematics

In *Prior Analyticus* and *Posterior Analyticus*, part of *Organon*, Aristotle expounds his ideas about logic and describes the syllogism.

Medicine & health

Aristotle incorrectly considers the heart to be the center of intelligence. He identifies five senses common to all humans: sight, hearing, taste, smell, and touch. *See also* 450 BCE MED; 300 BCE MED.

Physics

Aristotle rejects atomism because it implies the existence of a vacuum. He describes motion as requiring a continued force. *See also* 430 BCE PHY.

Transportation

The geographer Strabo the Younger publishes the first *Periplus* ("coast pilot"), a guide to the ports and rivers of the Mediterranean world, giving distances between points, locations for fresh water, and other information useful to sailors. *See also* 300 BCE EAR.

340 BCE

Transportation

About this time or shortly afterward an unknown shipbuilder, probably a Phoenician, starts building ships with one or two banks of oars with each oar

propelled by multiple rowers. Historians believe that the name of the type of ship became based on the number of rowers per oar multiplied by the number of banks. Thus, a quadrirreme instead of having four banks of oars, each with a single rower, might have one bank with four files of rowers or two banks with two rowers per oar. Because of the length of the oars required, each rower must stand and fall back with each stroke; this provides additional power. *See also* 399 BCE TRAN.

332 BCE

Tools

Catapults that throw stones instead of darts are mentioned for the first time in connection with the siege of Tyre by Alexander the Great. *See also* 397 BCE TOOL; 100 CE TOOL.

331 BCE

Construction

At the direction of Alexander the Great, the Macedonian architect Deinokrates lays out the new city of Alexandria on the Nile delta in Egypt. Its central north-south and east-west streets are each 14 m (46 ft) wide, dividing the city into four quarters, each with its own character. The plan is completed later by Ptolemy I, who joins several rocky islands and builds a long causeway to form two harbors set off by the famous Lighthouse of Pharos (named after the island on which it is built). *See also* 283 BCE CONS.

330 BCE

Astronomy

Greek astronomer Callippus

[b. Cyzicus (Turkey), c. 370 BCE, d. c. 300 BCE], a student of Eudoxus, is a careful observer who shows that at least 34 spheres are needed to account for the movements of the stars, Moon, and planets. *See also* 380 BCE AST; 140 CE AST.

Biology

Theophrastus [b. Eresus, Lesbos, Greece, c. 372 BCE, d. Athens, c. 287 BCE] writes major works describing and classifying plants, laying the foundations of botany. *See also* 350 BCE BIO.

Earth science

Theophrastus classifies 70 different rocks and minerals, doing the first work known on rocks and minerals.

Theophrastus, in *The Book of Signs*, the first known work on weather forecasting, tells how to predict the weather from common signs, such as a red sky at night or a ring around the Moon. *See also* 1337 EAR.

Ecology & the environment

Theophrastus describes relationships within communities of organisms.

315 BCE

Transportation

The successor of Alexander in Macedon, Antigonus the One-Eyed [b. 382 BCE, d. 301 BCE] and his son Demetrius, in charge of his navy, arrange to have Phoenician shipyards build warships with six and even seven files of rowers, eclipsing in size the quinqueremes introduced by Dionysius of Syracuse. *See also* 399 BCE TRAN; 301 BCE TRAN.



VIA APPIA The Via Appia ("Appian way") is largely gone, but a few sections remain where one can find parts of the old road — amazingly still in use although rather bumpy. Since burials were not permitted within the walls of ancient Rome, the parts of the old road just outside the city were lined with tombs and monuments, the remains of which are still visible beside the road.

312 BCE

■ Construction

The Via Appia, from Rome to Alba Longa (later extended to Capua and Brindisi), and the first Roman aqueduct, the Aqua Appia, bringing water underground to Rome from springs 16 km (10 mi) away, are built by Appius Claudius Caecus. *See also* 530 BCE CONS; 272 BCE CONS.

310 BCE

↳ Communication

Eudemus of Rhodes [b. Rhodes, Greece, c. 350 BCE, d. c. 290 BCE], a student of Aristotle's, combines his lecture notes with those of Aristotle and recollections from memory to produce the works of Aristotle as we know them. *See also* 350 BCE AST.

Σ Mathematics

Eudemus of Rhodes writes histories of arithmetic, geometry, and astronomy, now lost. The *History of Geometry* and *History of Astronomy*, however, are cited as the principal sources for many later histories of the subjects, so their contents are well known. *See also* 320 CE MATH.

I Tools

The Chinese invent a form of bellows, known as the double-acting piston bellows, that produces a continuous stream of air. Such bellows are unknown in the West until the fourth century CE. *See also* 300 CE MATR.

307 BCE

↳ Communication

Demetrios Phalereus persuades Ptolemy I (Ptolemaios

Soter) to collect copies of all known books at Alexandria in an institution known as the Library. The project is furthered by nearly all of the remaining Ptolemaic rulers of Egypt. At its height, the Library probably contains almost 750,000 books on papyrus scrolls — although some may have been duplicates since it is likely that not that many works were written in Antiquity. *See also* 48 BCE COMM.

301 BCE

↗ Transportation

By this year the navy of Demetrius of Macedon includes ships that have eight, nine, ten, and eleven files of rowers. There is even one ship with thirteen. *See also* 315 BCE TRAN.

300 BCE

★ Astronomy

Hellenic astronomers in Alexandria build an observatory that employs large tools for measuring small angles between stars. *See also* 1008 CE AST.

■ Construction

Romans and Hellenic Greeks begin to add flower gardens to the inner courts of their Mediterranean-type houses. The concept of a garden was introduced by the Persians and had been unknown previously in Greece and Rome.

The Adena people build the Great Serpent Mound in the Ohio valley, a mound in the shape of a serpent holding an egg in its mouth. The mound, measured along the body of the serpent, is 328 m (1254 ft) long.

Cast iron in China

The iron of the early Iron Age could not be melted and cast. Pure iron melts at 1535°C (2795°F), far too high for the first iron foundries. Early blacksmiths took advantage of iron ores that smelt into iron at moderately low temperatures without melting. The result was a mass oddly called a *bloom* from an old English word for "lump of metal." But nonmetals from ore are still mixed with iron in the bloom after the reduction. The impurities have to be worked out of the bloom by pounding until wrought iron is free of most of them (*wrought* is an old past participle of *work*). While pounding, the iron can be shaped into useful forms, such as blades or shields, but since wrought iron is never melted, the shapes must be simple. An iron pot is possible but difficult, and such a pot is about as far as one would want to go in shaping wrought iron.

About 300 BCE ironworkers in China discovered that burning iron ore mixed with charcoal produces a thick metallic liquid instead of a bloom. We now know that carbon from the charcoal mixes with the iron to produce an iron alloy with a melting point that can be as low as 1130°C (2066°F). This temperature is exceeded by the hot-burning charcoal. The hot liquid can be poured into a mold where it cools into hard, durable (but brittle) cast iron.

Cast iron is not really iron, and not all iron that is melted and cast is cast iron. In today's usage, cast iron is one of a number of alloys of iron with carbon (and less importantly silicon, manganese, and other elements). Steel is also partly iron combined with carbon, but the carbon in steel has entered into chemical combination with iron. In cast iron there is more carbon than in steel — in general, more than one part in fifty — and the carbon exists in flakes or other forms embedded in the iron. When the metal ancients knew as iron became completely melted, it could be cast, hence the name *cast iron*.

Although they did not know that the new method worked largely because charcoal is almost pure carbon, the Chinese quickly appreciated the advantages of cast iron over wrought iron. They also soon learned to vary the recipe to produce cast iron with different qualities, such as forms that were less brittle when cooled. The ability to cast the new alloy meant that all of the techniques previously developed for casting bronze or gold could be adapted. Complex shapes could be made in one operation. With wrought iron much working was required for even simple shapes.

Cast iron became an important part of Chinese life and public works. Even before cast iron became available in Europe, Chinese production was reaching levels of over 150,000 tons a year.

Parts of the Great Wall of China are built by various warlords during the Warring States Period. *See also* 214 BCE CONS.

Earth science

Pytheas [b. Greece, c. 330] sails into the Atlantic Ocean and observes much higher tides than in the Mediterranean Sea. He reports that tides are controlled by the Moon. *See also* 1687 CE EAR.

Dicaerchus of Messina (Sicily) [b. c. 355 BCE], a student of Aristotle's, develops a map of Earth that is on a sphere. It has lines of latitude based correctly on the lines where the noonday Sun is at a given angle on a particular day. *See also* 380 BCE COMM; 116 CE COMM.

Food & agriculture

The turkey is domesticated in Mexico.

Materials

The Chinese *Book of the Devil Valley Master* contains the first known reference to a lodestone's alignment with Earth's magnetic field. The lodestone is called a "south-pointer" although it was evidently used for divination, not for finding south. *See also* 1050 BCE TRAN; 83 CE TOOL.

The Chinese invent cast iron. *See also* 200 BCE MATR.

Mohist writings in China describe the first known use of poison gas in warfare. The Mohists were followers of Mo-Tzu, a fifth-century BCE Chinese philosopher.

Mathematics

The Museum is built in Alexandria, a home for scholars and artists of all types, but essentially the center of Hellenistic mathematics.

Euclid writes his *Elements*, 13 books that prove all that was known of geometry and numbers in his time, deducing the entire body from a small set of axioms and five postulates. Modern writers have criticized some of the axiomatic bases of the *Elements*, but the conclusions are still accepted as a consistent approach to geometry. *See also* 430 BCE MATH.

In Central America the Maya develop a place-value system based on 20, with separate symbols for ones and fives. The Maya may be the first to introduce a symbol for zero. *See also* 500 BCE CONS.

In China numerals are used for a place-value system based on ten. The *Chou suan ching*, among the oldest mathematics classics from China, is written. *See also* 540 BCE MATH.

Before this time, the Chinese develop the first magic squares. These are arrays of numbers chosen so that the sum of the rows, columns, and diagonals are all the same number. The first, known as the *lo shu* and said to have been observed on a turtle's shell, is the following array (which adds to the "magic" number 15):

4	9	2
3	5	7
8	1	6

See also 880 CE MATH.

♥ Medicine & health

Herophilus [b. Chalcedon (Istanbul), c. 335 BCE, d. c. 280 BCE] dissects the human body. He is believed to be the first to do so publicly. He claims the brain is the center of the nervous system. *See also* 500 BCE BIO.

Epicurus argues that organs develop through exercise and weaken when not used.

I Tools

Aineias the Tactician describes the portcullis, a gate overlaid with iron (later entirely of iron) that can be lowered at the entrance to a fortress to prevent attackers from gaining entrance.

A type of sundial known today as the hemicycle of Berosus is invented. It is a bowl with lines on its inner surface to mark the daylight hours when the shadow of a horizontal projection (gnomon) falls on them. For correct solar time, the hemicycle must be level and face due south. *See also* 620 BCE TOOL.

The screw is invented for fastening and other uses but is little used since all screws must be made by hand at this time. *See also* 60 CE TOOL.

Convex lenses are introduced in Carthage (Tunisia). *See also* 3000 BCE TOOL; 1020 CE PHY.

↗ Transportation

The Chinese invent a form of harness that is pushed by a horse's chest instead of a horse's throat, a great improvement that was not to be adopted in the West until the eighth century CE. *See also* 4000 BCE TRAN.

283 BCE

■ Construction

The Pharos Lighthouse is built at Alexandria by Sostratos of Knidos under the direction of the first two Ptolemies. It stands between 116 m and 134 m (380 and 440 ft) tall — it is not sure which cubit ancient writers used — and is made from hard stone with lead used as mortar. The lower section has a square cross-section and contains about 50 rooms. Surmounted on this is a tower with an octagonal cross-section topped with a cylindrical tower. A fire burned in the top tower night and day so that during the day mariners could see its smoke while at night they could use the light. *See also* 331 BCE CONS.

280 BCE

■ Construction

Chares of Lindos completes the Colossus of Rhodes, one of the Seven Wonders of the World. It is about the height of the modern Statue of Liberty in New York Harbor — between 27 and 37 m (90 and 120 ft) and is built from brass plates each a couple of cm (about an in.) thick attached to an iron framework supported by stone columns. The work is done in stages from a growing mound of earth so that the workers are always at the level of their work. Afterward, the mound is removed to reveal the completed statue. *See also* 224 BCE CONS.

Roman consul Manius Curius Dentatus [d. 270 BCE], conqueror of the Sabines, orders the marshes at Sabine Rieti drained by means of a 800-m (2624-ft) canal partly cut in

rock and routed so that it forms a dramatic waterfall into the river Nera.

↗ Transportation

Under Ptolemy II, the canal linking the Nile to the Red Sea is either completed or reopened. It had been begun by Pharaoh Necho about 300 years earlier and either completed or almost done so by Darius the Persian (who, according to Diodorus Siculus stopped short of finishing it because he feared that a higher Red Sea would flood the Mediterranean; Ptolemy installed a dam that prevented any such flooding). *See also* 500 BCE TRAN; 100 CE TRAN.

275 BCE

♥ Medicine & health

Erasistratus [b. Chios (Greek Aegean island), c. 304 BCE, d. Mycale (Samsun Dağı, Turkey), c. 250 BCE] performs public dissections. He declares that veins and arteries are connected and that arteries carry air from the lungs to the heart, where they become “animal spirits” that are carried from the heart to the rest of the body, while the veins carry blood. He observes that the nerves are connected to the brain and believes that there is a “nervous spirit” carried by them to the body. *See also* 450 BCE MED; 1240 MED.

272 BCE

■ Construction

The 64-km- (39.5-mi-) long Aqua Anio (Anio Vetus, or “old Anio,” so called after the Anio Novus is constructed) aqueduct, built largely below ground from stone, carries

about 182,500,000 L (48,200,000 gal) of water a day to Rome from springs feeding the Anio River in the upper valleys of the Apennines. It is built from 272 BCE to 269 BCE with money obtained as a result of the defeat of Pyrrhus. *See also* 312 BCE CONS; 144 BCE CONS.

270 BCE

★ Astronomy

Aristarchus [b. Samos, c. 310 BCE, d. Alexandria, c. 230 BCE] makes first rough calculation of the distance and size of the Moon and proposes that Earth and the planets revolve about the Sun. *See also* 350 BCE AST.

260 BCE

♥ Medicine & health

Erasistratus distinguishes between sensory and motor nerves. *See also* 170 CE MED.

250 BCE

↗ Energy

Although the origin of candles is obscure, they are mentioned by Philon [b. Byzantium (Turkey), c. 280 BCE, d. c. 220 BCE] about this time. Some think candles were invented by the Etruscans. Tapers (wicks dipped in wax once) and wax-impregnated reeds preceded candles, but the earliest form of artificial lighting device was the oil lamp. Even at this time, and for the next 2000 years, lamps are preferred to candles as light sources. *See also* 598 BCE ENER; 60 CE ENER.



Archimedes

[b. Syracuse, Sicily, c. 287 BCE, d. Syracuse, c. 212 BCE]

A few great humans have managed to excel in science, mathematics, and engineering, but none so noticeably as Archimedes. Mathematicians rank Archimedes among the greatest of all time; although his contributions to physics are not quite in the same class, they, like everything Archimedes touched, are elegant, original, and important.

Archimedes was born in Syracuse in southeastern Sicily, the principal Greek city-state on the island. Syracuse had a long tradition of intellectual achievement, having been for a time the home of both Aeschylus and Pindar. Nevertheless, Alexandria was the center of learning for the Hellenic world, and Archimedes is said to have studied there.

Archimedes considered his greatest achievement to be the discovery of how to calculate the volume of a sphere by comparing it with a similar-sized cylinder. Accordingly, a sphere inscribed in a cylinder was used to decorate his tombstone. More than a hundred years later the Roman Cicero was still able to locate and restore it, but the grave has subsequently been lost.

❖ Materials

According to tradition, parchment is invented about this time in Pergamum (Bergama, Turkey), from which its name is derived. Parchment is animal skin treated so that it can be written on both sides. Vellum, which may have originated later, is often taken to be parchment made from very young or unborn animals. *See also* 2500 BCE MATR; 250 CE MATR.

Philon of Byzantium advocates the use of bronze springs in catapults and experiments with the expansion of air by heat.

Σ Mathematics

Archimedes shows that numbers can be written as large as needed, calculates a close value for π , and develops improved methods of finding areas and volumes enclosed by curves or curved surfaces. *See also* 430 BCE MATH.

I Tools

Archimedes works out the principle of the lever and other simple machines. He demonstrates this by launching a large ship by himself. He may have invented the compound pulley and used this in his demonstration. He invents the Archimedean screw, still

used to lift water from rivers. *See also* 390 BCE TOOL; 880 PHY.

Philon of Byzantium builds a cardan joint, a form of universal joint using two interlocked forks, although traditionally this device has been attributed Girolamo Cardano. Philon also describes a primitive form of the chain-and-sprocket drive (now used in bicycles) and an early application of an undershot water wheel to power a bucket-and-chain water hoist. Shortly after this time other evidence suggests that water wheels were employed in grinding grain, although the connection between these and Philon's work, if any, has been lost. Philon also designs a chain drive for use in repeat loading of a catapult. In his book *On the Lifting of Heavy Weights* he describes a system of gears. *See also* 25 BCE ENER.

240 BCE

⊕ Earth science

Eratosthenes of Cyrene [b. Cyrene (Shahhat, Libya), c. 276 BCE, d. Alexandria, c. 194 BCE] calculates Earth's circumference, finding a value 15 percent higher than present estimates or even closer, depending on what one assumes about the actual

length of the Greek measure called a stadium. *See also* 450 BCE AST.

Eratosthenes gives the first correct explanation for the annual flood of the Nile, relating it to rains over lakes in East Africa that are the Nile's source.

Σ Mathematics

Eratosthenes invents the sieve of Eratosthenes, a method that discovers all prime numbers (whole numbers with no whole-number factors other than one and themselves) up to a given prime factor. He also develops a mechanical device that can be used to double the cube. *See also* 420 BCE MATH.

230 BCE

I Tools

Artifacts discovered since 1936 in and around Baghdad and at the Baghdad Museum are possibly the oldest known electric batteries, apparently used for electroplating about this time. These discoveries of pottery jars lined with copper, closed with an asphalt plug, and containing remains of iron rods, could explain the production of extremely thin layers of silver and gold on certain objects from Antiquity. Further evi-

dence that electroplating was the intended use of the jars is that similar apparatuses are used today by local silversmiths in the Baghdad region, suggesting that the tradition has persisted since Roman times.

224 BCE

■ Construction

The Colossus of Rhodes, one of the Seven Wonders of the World, is toppled during an earthquake. Its remains lie in place until 656 CE, when Arabs cart it away for scrap metal. *See also* 280 BCE CONS.

219 BCE

→ Transportation

Emperor Shi Huangdi [b. 259 BCE, d. 210 BCE] constructs the Magic Canal linking two rivers, one flowing south and the other north. The canal, built originally for military purposes, connects the north-flowing Xiang River, a tributary of the Yangtze, to the Li River, which joins other rivers that eventually reach Canton. Although only 32 km (20 mi) long, the canal enables a ship to sail from Canton (or anywhere else on the China Sea) to the latitude of present-day Beijing in inland China. *See also* 280 BCE TRAN; 133 BCE TRAN.

Inventions of Archimedes

While in Egypt, Archimedes invented the device that is mostly closely associated with him by name, the Archimedean screw. This is a helix in a tube that, when turned in the proper direction, raises a fluid in which the bottom of the tube is immersed to the top of the tube. Unlike a vacuum pump, the Archimedean screw is not dependent on air pressure and can raise water higher than the 10-m (30-ft) limit of vacuum pumps. The screw is still used for irrigation and other purposes today.

Another invention attributed to Archimedes is the orrery, a kind of planetarium in which model planets are moved by clockwork to simulate the movements of actual planets (in his time, in Ptolemaic epicycles, not in Keplerian ellipses). Such devices were made in Hellenic times, and it is probable that Archimedes made one, although less probable that he had the original idea for the mechanism.

During Archimedes' time Syracuse was ruled by a cousin, King Hiero II, who kept in close touch with the great engineer. Although Archimedes was reputed to be interested only in his intellectual pursuits, Hiero got him involved in public demonstrations of his inventions, a famous case of fraud detection, and the defense of the city against the Romans.

Archimedes is often said to have discovered the lever, but humans had been using levers for thousands if not millions of years. He did work out the mathematics of simple machines and, in the process, may have discovered the compound pulley. According to the story, after he remarked, "Give me a place to stand on and with a lever I will move the whole world," Hiero challenged Archimedes to a demonstration. Archimedes obliged by using compound pulleys to launch single-handedly one of the largest ships made up to that time, complete with crew aboard.

The story of Archimedes' discovery of the hydrostatic principle while in his bath and his subsequent run naked through the city crying "Eureka" is by far the most famous association with Archimedes in the public mind. The detection of a fraudulent amount of gold in a crown Hiero had ordered was accomplished by measuring the crown's density using the water displaced when the crown was submerged to find the volume. Despite the detailed story related by Vitruvius of this event, it seems that the concept of density was generally known previously.

Instead, Archimedes apparently discovered that a body immersed partly in a fluid displaces a mass of the fluid equal to the mass of the body. This principle extends beyond the concept needed to detect the fraud in the manufacture of the crown.

The details of Archimedes' defense of Syracuse are less generally known. Apparently, he devised a number of improved catapults and crossbows that pushed back ordinary waves of attackers. When the Roman general Marcellus brought out his own "secret weapon," a kind of seagoing siege vehicle, Archimedes used levers to drop huge boulders on the attackers, sinking the ships. Another story is that he focused the Sun's rays with mirrors on the ships to set them afire, but this is unlikely. Archimedes had investigated the parabola and therefore might have once demonstrated how to set fire to a nonmoving object from a distance with solar radiation focused by a parabolic mirror. But technology of that time — or this, for that matter — was not up to creating a mirror with the light-gathering power and focal length as any use as a weapon of war.

Marcellus's army finally managed to find a weak spot in the defense of the city and overran it. Although Marcellus had instructed his soldiers to spare Archimedes, one of them encountered him contemplating a geometric figure drawn in the sand (the common way to do geometry at the time). When the soldier damaged the figure and Archimedes protested, the soldier killed him.



ARCHIMEDEAN SCREW One of the inventions of Archimedes, this device has been used for lifting fluids to a higher level for over 2000 years. The lower end is placed in the fluid and as the mechanism is rotated, the fluid flows up through the hollow screw. It is used today for irrigation in parts of Asia and as a part of some modern tools in the United States.

214 BCE

Construction

General Meng Tian, working under the orders of the Chi-

nese Qin emperor Shi Huangdi, completes building the 2400-km- (1500-mi-) long Great Wall in the north, running from the Yellow Sea to the deserts of what is now

Turkistan. Meng Tian's workers take just seven years (this date is estimated; Shi Huangdi is now thought to have taken power in 221 BCE). *See also* 300 BCE CONS.

210 BCE

Archaeology

Chinese emperor Shi Huangdi, or Ch'in Huang Ti, is

210 BCE–200 BCE

buried with more than 6000 statues of soldiers to guard his grave, which also features a relief map of his empire with the rivers formed from flowing mercury and the heavens depicted above. *See also* 1600 BCE CONS.

→ Transportation

The largest naval vessel of the classical age is built by Ptolemy IV (Philopater) [ruled 221–205 BCE, d. 205 BCE] of Egypt. It has 4000 rowers in 40 banks, and carries as many as 3250 others as crew and fighting marines. This super-galley is a catamaran over 120 m (400 ft) long. It is never used in battle, however. *See also* 200 BCE TRAN.

As a result of the largest naval vessel being built by Ptolemy IV (Philopater) of Egypt, the dry dock is invented to launch it, since the usual means of launching by dragging across land by crews of workers would be too difficult. Instead, the ship is built in a channel that is connected to the sea so that when the ship is complete the channel can fill with water and launch the ship. Technically, this is the reverse of the more common function of a dry dock, which usually admits the ship to the channel, then the water is removed, leaving the ship “dry” for repairs.

200 BCE

▲ Archaeology

The last stronghold of the Olmec, now called Tres Zapotes (Mexico), falls into ruin. This “mother civilization” for mesoamerica had been in decline since 500 BCE.

See also 650 BCE COMM; 200 CE COMM.

★ Astronomy

The astrolabe, used for determining the level of elevation of the Sun or another star, is invented and introduced to Hellenic sailors. Some have attributed it to Apollonius of Perga [b. c. 262 BCE, d. Alexandria, 190 BCE] (shortly before 200 BCE) or to Hipparchus [b. Nicaea, c. 190 BCE, d. c. 120 BCE] (shortly after 200 BCE). Hipparchus certainly used some tool of this type in his astronomical research. *See also* 1391 CE TOOL.

↳ Communication

Ctesibius of Alexandria [b. c. 285 BCE, d. c. 222 BCE] builds a water organ, called in Latin a *hydraulis*. The *hydraulis* is a pipe organ in which air is supplied at constant pressure by water in a bell that obtains additional air from a bellow. Models (in Carthage in 1885) and portions of actual instruments from Antiquity have been found (near Budapest). The *hydraulis* is the instrument that Emperor Nero played on several infamous occasions. *See also* 120 CE TOOL.

■ Construction

Many buildings in Rome are three-story apartment houses called *insulae*, or “islands.” *See also* 100 BCE CONS.

◊ Materials

The Chinese develop a malleable form of cast iron. *See also* 300 BCE MATR; 400 CE MATR.

Concrete is used in the Roman town of Palestrina in Italy. *See also* 100 BCE MATR.

Σ Mathematics

Apollonius of Perga writes *Conics*, a systematic study of the properties of the conic sections (circle, parabola, ellipse, hyperbola).

♥ Medicine & health

Diocles [b. Carystus, Euboea (Greek island), c. 240 BCE, d. c. 180 BCE] writes the first known anatomy book and is the first to use the term *anatomy*. *See also* 170 CE MED.

I Tools

The development of gears leads to the ox-powered water wheel, used to raise water to the level of fields for irrigation purposes. *See also* 700 BCE FOOD.

Ctesibius of Alexandria improves the water clock, making it the most accurate timekeeping device available for nearly 2000 years. He also invents a water pump consisting of a cylinder and piston and two valves, one at the intake and one at the outlet. When the piston is lifted, the valve at the inlet is open, admitting water while the valve at the outlet is closed. When lowering the piston, the valve at the inlet is closed and the one at the outlet is open. He also invents a form of air gun, called a wind gun. *See also* 1380 BCE TOOL; 724 CE TOOL.

→ Transportation

Shipbuilders in the Mediterranean have begun to introduce three-masted vessels (a foremast with a distinctive forward rake called an artemon, the main, and a mizzenmast at the rear). A large ship, the *Lady of Syracuse*, whose building was supervised by

Archimedes (although the ship was designed by Archias of Corinth) may have been the first of these. *See also* 650 BCE TRAN; 1 CE TRAN.

In the South Pacific Polynesians colonize the Marquesas islands. *See also* 500 CE TRAN.

180 BCE

■ Construction

An aqueduct is built to supply the citadel of Pergamon, built on a knoll with an elevation of 332 m (1089 ft), from a spring in the mountains at an elevation of 1173 m (3850 ft).

Along the way, the aqueduct passes through two valleys with low points of 172 m (564 ft) and 195 m (639 ft) as well as the ridge of 233 m (764 ft) between them. This is accomplished by using a bronze or lead pipe to cross the low points of the aqueduct and using water pressure (as high as 20 atmospheres in the lowest point) and a siphon effect. *See also* 272 BCE CONS; 144 BCE CONS.

170 BCE

II Food & agriculture

The first written record of a professional baker that has come down to today identifies the origin of baking for the public as occurring in Rome while it is warring with Macedonia.

150 BCE

★ Astronomy

Hipparchus makes the first star map, calculates the correct distance of the Moon from Earth, and observes the precession of the equinoxes, a wobble of

Salt and the fall of civilization

A common theory about the rise of civilization is that the need for state organization of irrigation became the prime mover that led to all other changes. Irrigation may also be implicated in the *fall* of civilizations.

Mesopotamia provides the main example. When large-scale irrigation began in the Tigris and Euphrates river valleys, it was accompanied by urban growth, writing, empires, monumental construction, and such technological innovations as the wheel. The former desert prospered and was central to the growth of human population and influence for about 4000 years. The former desert land became known as the Fertile Crescent. Today the Fertile Crescent is mostly desert again.

Although there are several factors involved in the decline back into desert, salt in the soil appears to be the major one. The process of irrigation reverses the normal flow of water through the soil. Outside the desert, soil is watered mainly by rain that carries salt in the soil deeper into the ground. Evaporation in an irrigated desert causes water in the soil to move from

lower levels toward the top of the soil as the Sun dries out upper layers. Such movement carries salt toward the surface.

Most plants cannot grow in salty soil. Romans, appreciating this, sowed salt on the ruins of Carthage after its defeat to prevent it from returning to power.

Flooding can erase the effects of irrigation by washing the salt back into lower regions of the soil. Egypt and China, subject to floods, have had fewer problems with salty soil than has Mesopotamia. In Egypt, however, damming of the Nile in 1964 prevented flooding but also started a buildup of salt in the soil.

The Maya practiced irrigation in a rain forest, where salt buildup would seem less likely than in a desert. Nevertheless, it appears that they too managed with irrigation to reverse the normal flow of minerals through the porous limestone soil of Central America, contributing to the collapse of their civilization as well.

Today farmers in other irrigated regions, such as Pakistan and the San Joaquin Valley in the United States, face similar buildup of salt in the soil.

Earth's axis that revolves once every 26,000 years. His lunar distance, which is sensibly given in terms of maximum and minimum possible figures as between 59 and 67½ Earth radii (the actual average distance is 60 Earth radii), is based on close observations of eclipses and a geometric model that relates the size of the disks covering each other. *See also* 300 BCE AST; 300 CE AST.

Communication

Historian Polybius [b. Arcadia, Greece, c. 200 BCE, d. c. 118 BCE] describes communication by means of fire signals. *See also* 430 BCE COMM.

Materials

Silver is so rare and costly in Rome that a visiting delegation from Carthage entertained by all the richest families in Rome encounters the same set of silver dinnerware each night.

A large decorated silver bowl

70 cm (27 in.) in diameter, now known as the Gundestrup Cauldron, variously claimed as Germanic, Celtic, and Thracian and dated from some time in the century prior to this date, depicts such enigmatic figures as a man wearing a torc (neck ring) and antlers, elephants, and a woman flanked by birds. It may have been made from melted Persian coins by craftpersons of a separate ethnic group, similar in some ways to present-day Roma (Gypsies).

Transportation

First science fiction writer Lucian of Samosata [b. Samosata (Samsat, Syria), c. 125 CE, d. c. 180 CE] describes in *True History* a Greek ship that travels to the Moon by winds and waterspouts and later in *Icaro-Menippus* a hero who flies to the Moon via wings removed from large birds. Notably, Lucian envisions the Moon, the Sun, and

also the planets as bodies where creatures live, not unlike Earth.

148 BCE

Materials

During the final siege of Carthage (Tunisia) by the Romans, the women of Carthage sacrifice their long hair to make strings for their soldiers' bows. It is not much use because hair creeps badly when stressed and does not store strain energy over significant periods of time. *See also* 814 BCE ARCH.

144 BCE

Construction

The 92-km- (56.7-mi-) long Aqua Marcia, completed from 144 BCE to 140 BCE, is the first Roman aqueduct with substantial elevated portions, about 11.1 km (6.9 mi) built entirely from stone on arches. It carries about 194,500,000 L

(51,400,000 gal) of water a day. *See also* 272 BCE CONS; 125 BCE CONS.

140 BCE

Materials

The Chinese make paper. It is used as a packing material and for clothing, but not yet for writing. *See also* 105 CE MATR.

Tools

A Chinese text describes an incense burner suspended in a system of concentric rings so that it remains horizontal. This is the first Chinese description of such a universal joint, invented by Fang Feng. *See also* 189 CE TOOL.

133 BCE

Transportation

The capital of China at this time, Chang'an (Xi'an), is linked by a 145-km (90-mi) canal to the Huang He (Yellow River). *See also* 219 BCE TRAN.

130 BCE**Food & agriculture**

In 126 Chang Ch'ien [b. c. 172 BCE, d. c. 114 BCE] brings wine grapes — *vinifera* — to China from the West. *See also* 53 BCE COMM.

126 BCE**Communication**

Reports from an expedition to the West, from 138 to 125 BCE

and led by Zhang Qian of the Han dynasty in China, are among the many influences that lead to the establishment of the Silk Road, the trade corridor from China to the West. *See also* 53 BCE COMM.

125 BCE**Construction**

The 20-km (12-mi) long Aqua Tepula is the first aqueduct to use the arches of the Aqua

Marcia as part of its route so that it can serve more elevated portions of the city of Rome. It carries only 18,000,000 L (4,800,000 gal) of water a day. *See also* 144 BCE CONS; 33 BCE CONS.

119 BCE**Materials**

The Han dynasty in China nationalizes cast iron and salt

production. *See also* 200 BCE MATR; 31 CE TOOL.

110 BCE**Transportation**

The Chinese invent the collar harness for horses, the most efficient form of harness to this day. It is not used in the West until the Middle Ages. *See also* 100 CE TRAN.

Domes, beams, columns, arches, trusses

Structurally, the main problem for any building is how to keep the roof from falling. Most early buildings were simple domes, with roof and walls a single entity. It was not clear where the walls stopped and the roof began. Probably this method started in imitation of huts built by tying together bent saplings rather than as a conscious engineering choice, but it was still effective. All buildings must contend with outward forces on walls, but forces on domed buildings are at an angle instead of directly outward. As domes grow larger, the outward component tends to overwhelm the downward component that is holding the wall together.

One-roomed domed houses were eventually abandoned in most cultures for buildings with vertical walls and flat roofs. The first rectangular buildings were sized by the length of available wooden beams that could be used as the basis of the flat roof. The force of the roof was directed down on the walls, which could be joined to the roof for greater security. Several rooms could also be built adjacent to each other to make a larger building.

Later, builders introduced columns in the interiors of rooms to hold up the ends of some beams, allowing construction of larger rooms. Horizontal beams above windows and doors that support walls are called lintels, so construction that relies on beams held up by columns is often called post-and-lintel construction. Post-and-lintel construction was the basis of most Egyptian and Greek architecture, even the famous Greek temples. It is still used today, along with other construction techniques.

Early dome houses built from bricks had each layer of brick run in a circle of a somewhat smaller radius than the one

below it, with each brick resting partly on the lower course and partly cantilevered off into space. A section (slice) across such a building is called a corbeled arch. A true arch uses wedge-shaped bricks or blocks; the result in its simplest form is a semicircle. Although both the corbeled arch and the true arch were known to the builders of the earliest civilizations, a devotion to mass-produced rectangular solids for most construction meant that the corbeled version was much more common. The Romans, on the other hand, preferred the greater structural strength of the true arch, and also tended, even for rectilinear structures, to use bricks and stones that were wedge shaped.

The arch is one of the hallmarks of Roman architecture. Even after concrete replaced brick and stone as the basic building material, Roman builders favored arches. Most Roman arches have semicircular or curved tops placed on vertical columns. Because the curved top directs some force laterally, as well as vertically, such arches often need some support from the sides. While this can be supplied in many ways by one sort of buttress or another, Roman builders often used additional arches for support, resulting in several arches in a row (called a *course*). The columns on the outside of such a course still needed some sort of buttress to withstand the lateral forces.

A relief picture on a column raised to honor Emperor Trajan's victory over the Dacians in 105 ce reveals that the Romans also knew another construction method, that of the truss. The truss is a brace that forms a triangle, the only rigid polygon. Trusses eventually became a major feature of construction. Frameworks of trusses hold up many older bridges still in use today and are part of the construction of all houses with peaked roofs. The truss does more than simply support the roof in such houses, for it also spreads the stresses in different directions.

109 BCE**Transportation**

Roman consul Marcus Aemilius Scaurus [b. 163 BCE, d. 89 BCE] has the Po Valley drained to make new land for veteran soldiers, using the canals to connect the Po to Parma for boat passage. *See also* 12 BCE TRAN.

100 BCE**Chemistry**

Roman metalworkers produce mercury from the ore cinnabar. *See also* 25 BCE MATR.

Communication

The notebook, or *codex*, consisting of leaves of parchment sewn together on one side is in use in Rome. *See also* 868 CE COMM.

Construction

Antipater of Sidon, probably using earlier Hellenic guidebooks, compiles the earliest known list of the Seven Wonders of the World (a slightly different list is given somewhat later by Philon of Byzantium). The list consists of the Pyramids of Egypt, the Hanging Gardens of Babylon, the giant statue of Zeus at Olympia, the Temple of Diana at Ephesus, the Mausoleum at Halicarnassus, the Colossus of Rhodes, and the Lighthouse of Pharos. Of these, only the Pyramids of Egypt stand today. *See also* 224 BCE CONS.

Roman engineers learn shortly after this date how to rotate the arch to produce a dome. They use this extensively thereafter in construction of public buildings. Sometimes this is modified to produce what amounts to a square

dome, known as a cloister vault. *See also* 100 CE CONS.

Apartment houses in Rome, called *insulae* or “islands,” commonly reach five stories. *See also* 200 BCE CONS; 15 BCE CONS.

Energy

The Chinese use natural gas obtained by drilling in the ground. *See also* 400 BCE ENER; 1 CE TOOL.

Materials

Small, round glass skylights, the ancestors of windowpanes, are installed in houses of the later Roman Republic. *See also* 100 CE MATR.

The Romans discover that Pozzolana, volcanic ash from Puteoli, near Naples, makes excellent concrete that will set and keep its integrity even under fresh or salt water. *See also* 200 BCE MATR; 10 BCE CONS.

Glass blowing is developed, probably somewhere in the Levant (Syria, Lebanon, Jordan, or Israel), most likely by Phoenicians. *See also* 1370 BCE MATR.

People of the culture known as Paracas Necropolis from their burial ground on the Paracas peninsula of Peru produce what many archaeologists believe to be the finest textiles ever made by humans, embroidering on cotton and on the wool of the llama and its relative the vicuña. *See also* 6000 BCE MATR.

Mathematics

Theodosius of Bithynia [b. Bithynia (Turkey), c. 160 BCE, d. c. 90 BCE] writes *Sphaerics*, a treatise on the geometry of the sphere, written as a supplement to Euclid's *Elements*.

It provides a mathematical basis for the crystal spheres of Greek astronomy. *See also* 300 BCE MATH; 100 CE MATH.

Tools

Roller bearings from wood and bronze are used on the wheels of carts in what is now Denmark. *See also* 50 CE TRAN.

The Chinese invent the crank handle for turning wheels. *See also* 800 BCE TOOL; 50 CE TOOL.

In Illyria (Yugoslavia and Albania) and probably in western Anatolia (Turkey), water-powered mills are used for grinding grain. These are horizontal turbines that only work on swiftly running streams. With no gears, the upper horizontal stone turns at the same speed as the turbine, while the lower one is stationary. *See also* 25 BCE ENER.

Transportation

The Celts invent a swiveling pair of front wheels (sometimes called a bogie) to make steering easier on carts. *See also* 1100 BCE TRAN; 1340 TRAN.

The earliest form of the horseshoe is introduced in Western Asia and Eastern Europe. *See also* 1835 CE FOOD.

90 BCE**Transportation**

Historical Records of Ssuma Ch'ien [b. 145 BCE, d. 85 BCE] includes the first known reference to parachutes. *See also* 1783 CE TRAN.

85 BCE**Food & agriculture**

Gaius Sergius Orata develops

a system for heating seawater by circulating hot air beneath tanks. Its purpose is to promote faster growth in oysters that he then sells to wealthy Romans. *See also* 80 BCE ENER.

80 BCE**Computers**

The Antikythera mechanism, a complex bronze orrery (astronomical computing machine) of great accuracy, based on an intricate system of 24 gears and 13 axles, is built. It contains the first known differential gear and has sometimes been called the first computer. Its existence was revealed in 1901 when it was found by Greek sponge divers in a wreck off the island of Antikythera, although it was not explained until 75 years later by Derek de Solla Price. *See also* 1900 CE TOOL.

Energy

Gaius Sergius Orata begins to purchase neglected villas and to install a version of his home heating system, called the hypocaustum. The system uses a series of tanks propped up on short brick posts; a fire on one side of each tank warms it, and hot air from the tank circulates beneath the floors, warming the house. Orata also invents the *balneae pensiles*, raised bathrooms that are heated by means of ducts under the floor. He then resells the villas for vastly more than they cost him to acquire and modify. Similar systems are soon installed at public baths throughout Italy, but Orata is sued by his customers for “price gouging.” *See also* 85 BCE FOOD.

70 BCE

70 BCE

Communication

Marcus Tullius Tiro, a freed slave, develops a shorthand system, used by Cicero, Julius Caesar, and the emperor Titus. It will remain in use for about ten centuries. *See also* 1588 CE COMM.

60 BCE

Communication

Julius Caesar [b. Rome, July 12, 100 BCE, d. Rome, March 15, 44 BCE] invents a form of newspaper. News items, such as nominations, battles, etc. are written up in many copies called *acta diurna* and posted on main buildings in towns. *See also* 618 CE COMM.

55 BCE

Construction

The troops of Julius Caesar build a wooden trestle bridge that spans the Rhine, taking ten days for the feat and demonstrating the skill of Roman engineers — permanent bridges often take years to construct today, even over small streams. The Roman Rhine bridge, however, was intended for limited use. *See also* 490 BCE TRAN; 19 BCE CONS.

53 BCE

Materials

Roman soldiers fighting the Parthians of western Asia see silk for the first time in Parthian military banners. Their reports eventually lead to the creation of the Silk Road system of interchanging goods between China and the

Roman Empire. *See also* 126 BCE COMM; 500 CE MATR.

50 BCE

Biology

Lucretius [b. Rome, c. 99 BCE, d. Rome, c. 55 BCE] suggests that some organisms have adaptations that help them survive while others are less fitted to survival and become extinct. His famous poem *De rerum natura* ("on the nature of the universe") is published after his early death. *See also* 550 BCE BIO.

Communication

Lucretius describes how the illusion of motion can be created by sequential display of frames.

Physics

Lucretius endorses a modified view of the atoms proposed by Democritus. For example, Lucretius thinks that there must be a finite number of types of atom, none large enough to be visible, and that their natural motion is down, not in straight lines in random directions. *See also* 450 BCE PHY.

48 BCE

Communication

Julius Caesar removes hundred of thousands of volumes from the Library at Alexandria and ships them to Rome (with Cleopatra's permission). *See also* 307 BCE COMM; 40 BCE COMM.

46 BCE

Astronomy

Acting on the advice of Greek

astronomer Sosigenes [b. c. 90 BCE], the Julian calendar of three 365-day years followed by one of 366 days is introduced in Rome by Julius Caesar. As a result of changes to make the seasons correct, the year 46 BCE has 445 days, making it the longest year on record. The first leap years, due to an error of interpretation, will be three years apart, occurring in 45 BCE, 42 BCE, etc. until 9 BCE, by which time the year will again be off the seasons (by 13 days). Leap years will be abandoned for 16 years (reducing the error to 9 days) and then reinstated by Augustus in 8 CE. After that the four-year rule will be followed. *See also* 432 BCE AST; 123 CE AST.

40 BCE

Communication

During the fighting over control of Alexandria in the wake of the assassination of Julius Caesar, either part of the Library at Alexandria is burned or else the books that Cleopatra had given to Caesar in 48 BCE are lost. Marc Antony [b. Rome, c. 83 BCE, d. 30 BCE], now allied with Cleopatra, donates the 200,000-roll library from Pergamum (Bergama, Turkey) to Alexandria to replace the lost books. *See also* 48 BCE COMM; 269 CE COMM.

Construction

Lucius Cocceius Auctus designs and builds two tunnels to ease traffic bottlenecks around Naples, each about 3 m (10 ft) wide and varying in height from $\frac{1}{2}$ m (9 ft) to 21 m (70 ft). According to a report by Seneca, they were dark and dusty. *See also* 522 BCE CONS; 41 CE CONS.

Medicine & health

The *Ayurveda* is compiled from verbal sources that may date from hundreds of years earlier. It becomes the basic Hindu medical treatise and is still popular as an alternative medical text today. *See also* 170 CE MED.

36 BCE

Communication

A stone monument in Chiapa de Corzo (Mexico) contains the earliest known Mesoamerican date that appears to correspond to a real event. *See also* 199 CE COMM.

33 BCE

Construction

The 23-km- (14.2-mi-) long Aqua Julia aqueduct of Marcus Agrippa [b. Italy, 63 BCE, d. 12 BCE], like the earlier Aqua Tepula, uses the arches of the Aqua Marcia as part of its route so that it can serve more elevated portions of the city of Rome. It carries 50,000,000 L (13,200,000 gal) of water daily. *See also* 125 BCE CONS.; 38 CE CONS.

25 BCE

Energy

A book on architecture and engineering by Roman architect Vitruvius (Marcus Vitruvius Pollio) [b. c. 90 BCE, d. c. 20 BCE] also discusses astronomy, acoustics, sundials, and water wheels. His *De architectura libri decem* ("ten books on architecture") will remain the main source of knowledge about Roman construction until the Renaissance. The "Vitruvian" water wheel is the

PONT DU GARD AT NÎMES The old Roman bridge still stands, reflected here in the calm river. The bridge is a good example of how Roman engineers used arches in series to absorb the stresses from heavy stone or concrete construction.



first known instance of a vertical, undershot water wheel (the water runs beneath the wheel). Gearing is used to make the speed of the millstone one-fifth the speed of the wheel, a great improvement for grinding of grain. This type of wheel probably developed from the kinds of water wheels used for centuries for raising water for irrigation.

Materials

Vitruvius describes gold amalgam, that is, gold dissolved in mercury. *See also* 100 BCE CHEM.

19 BCE

Construction

On June 9 Roman general Marcus Agrippa completes the 21-km- (13-mi-) long Aqua Virgo aqueduct, which runs almost completely underground from springs on the estate of Lucullus to the Campus Martius. It brings 104,000,000 L (27,500,000 gal) of water a day to Rome. It has remained in use intermittently until the present day, although sometimes out of order for

hundreds of years. *See also* 33 BCE CONS; 2 BCE CONS

Agrippa builds the aqueduct at Nemausus (Nîmes), which features the Pont du Gard bridge over the Gardon River. The bridge has three tiers of arches 49 m (160 ft) high and is 274 m (900 ft) long. It is built of stone without cement or mortar and still stands today. An ingenious sluice with three channels is used to guarantee that the flow of water through the aqueduct remains constant. *See also* 40 BCE CONS; 2 BCE CONS.

15 BCE

Construction

About this time Emperor Augustus [b. September 23, 63 BCE, d. 14 CE] sets a limit of about 21 m (70 ft) on the height of buildings in Rome. *See also* 100 BCE CONS; 100 CE CONS.

Tools

The Dictionary of Local Expressions by Yang Hsiung [b. 53 BCE, d. 18 CE] indicates that the Chinese have invented the belt drive, which will not be known in Europe until 1430.

12 BCE

Transportation

Roman general Nero Claudius Drusus [b. 38 BCE, d. Germany, 9 BCE] joins the largest lake in what is now the Netherlands, the Flevo Lacus, to the Rhine with a canal (the Fossa Drusiana) that uses the Yssel River for part of the passage. *See also* 45 CE TRAN.

10 BCE

Construction

Herod the Great [b. 73 BCE, d. 4 BCE] has the first large harbor constructed in the open sea to support his new town of Caesarea Palestinae (near present-day Haifa). The harbor is constructed of giant blocks of concrete poured into wooden forms. *See also* 100 CE CONS.

2 BCE

Construction

Roman emperor Augustus has the 33-km- (20.3-mi-) long Aqua Alsietina aqueduct built underground to Traste-

vere. It carries only 15,800,000 L (4,200,000 gal) of water a day, making it the smallest of the 11 aqueducts that eventually supply Rome in Antiquity. Its water is not drinkable, however, for it was built to supply a 360-m (1181-ft) by 540-m (1800-ft) artificial lake designed for mock sea battles to amuse the Romans. *See also* 19 BCE CONS; 38 CE CONS.

1 CE

Construction

The Chinese build suspension bridges of cast iron that are strong enough for vehicles to cross. *See also* 415 CE MATR.

Transportation

The earliest known depiction of a ship's rudder dates from about this time in China. *See also* 1180 CE TRAN.

Sometime before the start of the Roman Empire, some ships are fitted with a small triangular topsail above the mainsail. *See also* 500 BCE TRAN.

Maps of the world

In Homer's time (c. 800 BCE), the map of the world showed the continental mass formed by parts of Asia, Africa, and Europe surrounded by a vast body of water, Oceanus.

Herodotus, however, felt that the Homeric world had too much water and not enough land. To balance things out, he replaced Oceanus with a great desert.

Symmetry was an overriding concern of the Greeks. For example, they noted that a line drawn between the Nile and the Danube would give a somewhat symmetrical version of the known world. But they obtained even more symmetry by carrying Pythagorean ideas over; that is, that Earth must be a sphere. Plato accepted this on purely geometrical grounds, but Aristotle offered a variety of proofs of sphericity from observation. Later Greek geographers accepted the spherical Earth as a matter of course and worked from there.

The Greek belief in symmetry resulted in the accidental insight that there must be a great continent in the Southern Hemisphere. Since the Greeks knew there was a great land mass in the Northern Hemisphere, they believed it must be balanced by one to the south. Pomponius Mela, writing about 43 CE, made Ceylon the northern tip of a very large *Antichthones* ("counterEarth"). This large continent was later known as *terra australis nondum cognita* ("the undiscovered southern continent"). By the 15th century, maps showed that Terra Australis had attached itself to southern Africa, effectively barring ships from reaching the East by sailing around Africa. When Bartolomeu Dias rounded the Cape of Good Hope in 1487, however, Terra Australis began to shrink.

Some maps from early in the 16th century, notably a Turkish map from 1513 and the Orantes Pinnaeus world map of 1532, show Antarctica of about the right size and location. Even the bays and mountain ranges are close to where they are now known to be. Some people think that these were copied from truly ancient maps prepared by a seafaring peo-

ple who had sailed the globe. It is more probable that among the many versions of Terra Australis, these came closest to the truth.

Another persistent tradition is that some maps before the time of Columbus and Magellan correctly located the Americas. The Portuguese who first reached Java are supposed to have seen a map there that showed South America. The Vinland map of the Northern Hemisphere, dated at about 1440 CE, shows North America. The question of whether it is a fake is still hotly debated, with one side finding the ink right for the 15th century and another finding the ink too modern.

The discovery of the north coast of Australia by Europeans (it may have been known to the Chinese as early as the 13th century) would seem to have justified the belief in a giant southern continent, but in the mid-17th century Abel Tasman circumnavigated Australia, shrinking the southern continent once again. Even in the 18th century, however, people continued to believe in the existence of the continent at the South Pole, arguing from the same premise of symmetry as had the Greeks. Alexander Dalrymple was the particular champion of the "Great Southern Continent," but he was passed over on the British government's expedition to find it. Instead, the expedition was put under the leadership of Captain James Cook. While the official purpose of Cook's voyage was to observe the transit of Venus from Tahiti, Cook also had secret orders to find the Great Southern Continent.

Cook's first voyage (1768–71) located New Zealand, but circumnavigation showed that it was not the missing continent. In 1772 he started out again, this time with location of the continent as his major goal. Cook reached within 75 miles of Antarctica but failed to find land. He concluded that the Great Southern Continent was either a myth or so close to the pole as to be beyond navigation. Finally, in the 19th century, various explorers reached land and the true nature of Antarctica gradually became known. The world map was finally complete on the basis of exploration, not just theoretical ideas.

The semilegendary Ko Yu invents the wheelbarrow, although this Chinese invention is also attributed to Jugo Lyang (Chu-Ko Liang) around 200 CE. See also 1220 CE TRAN.

5 CE

★ Astronomy

Chinese records mention a nova or comet seen around 5 BCE. This observation is associated by some with the star of Bethlehem. See also 2296 BCE AST.

Σ Mathematics

In China, mathematician Liu Hsin is the first person known to use a decimal fraction.

9 CE

I Tools

An adjustable caliper is in use in China. Built from brass along the lines of a modern adjustable wrench, it measures in tenths of a unit about the size of an inch.

12 CE

♥ Medicine & health

Thaddeus of Florence describes the medical use of alcohol in *De virtutibus aquae vitae* ("on the virtues of alcohol").

20 CE

⊕ Earth science

Geography by Greek geographer Strabo [b. Amasia, Pontus, (Amasya, Turkey) c. 63 BCE, d.

c. 25 CE] attempts to collect all the known geographical knowledge of Earth. The book is correct about the size of Earth and therefore posits that there must be unknown continents. See also 240 BCE EAR.

31 CE

I Tools

Chinese engineer Tu Shih invents the water-powered bellows for use in working cast



THE AQUA CLAUDIA Built by Caligula and Claudius, Rome's largest aqueduct failed in 62 CE after ten years use, but was restored by Vespasian and again by Titus. By 91 it was functioning steadily and continued to carry water to Rome with only minor repairs until the fall of the empire. Today the ruin of the aqueduct can be seen crossing the Campagna (countryside near Rome).

iron to make agricultural implements. *See also* 120 CE TOOL.

38 CE

■ Construction

Caligula [b. Antium, August 31, 12 CE, d. Rome, January 24, 41] initiates building of the 69-km- (20.3-mi-) long Aqua Claudia and the 87.5-km- (54.0-mi-) long Anio Novus aqueducts, both built on arches across the Roman Campagna, and both completed in 52 CE. Together they are able to carry 387,600,000 L (102,400,000 gal) of water daily to the highest hills of Rome, including the Palatine. *See also* 2 BCE CONS; 109 CE CONS.

40 CE

■ Construction

According to some sources Caligula orders a lighthouse some 38 m (124 ft) tall built at Boulogne, France. *See also* 283 BCE CONS.

■ Earth science

Greek sailors use monsoon winds to shorten the time of journeys from the Horn of Africa to southern India. *See also* 100 CE TRAN.

■ Medicine & health

De materia medica by Greek physician Pedanius Dioscorides [b. Anazarbus (Turkey), c. 40 CE, d. c. 90] deals with the medical properties of

about 600 plants and nearly a thousand drugs. *See also* 400 BCE MED; 170 CE MED.

41 CE

■ Construction

Roman emperor Claudius [b. Lugdunum, Gaul (Lyon, France), August 1, 10 BCE, d. October 13, 54 CE] orders work to begin on a 5.6-km (3.5-mi) tunnel through rock to drain Lacus Fucinus (Lago Fucino) to make new farmland. The project is directed by the aristocrat Narcissus. *See also* 40 BCE CONS; 52 CE CONS.

45 CE

→ Transportation

Roman general Gnaeus Domitius Corbulo [d. c. 67 CE] digs a ship's canal joining the Rhine with the Meuse River in what is now Germany. *See also* 12 BCE TRAN.

50 CE

□ Chemistry

In Alexandria, Mary Prophetissa (a.k.a. Maria or Miriam the Jewess), according to some reports, discovers hydrochloric acid and practices alchemy, producing the black metal sulfides that become one of the origins of the name "black art" for alchemy.

Why was the steam engine not used in Antiquity?

Western civilization in Antiquity forms a continuous society with different state organizations stretching from the time of Homer and Hesiod in Greece (c. 800 BCE) through the fall of the western Roman Empire, often dated as 476 CE, a period considerably longer than a millennium. The main societies, usually termed Greek and Roman, could more properly be termed Greek speaking and Latin speaking, although Greek includes several dialects, such as Ionian and Attic, Doric, Macedonian (perhaps not even Greek), and *koine*, the common Greek of later times. The period is called Classic with regard to its literature and philosophy.

Although Ionian, Greek, and Hellenic science was of the highest order found in ancient times — the Ionians of the seventh century BCE virtually invented science — there were few technological advances. The beam wine/olive press comes to mind as the most characteristic mechanical invention, although there were a few others. The Romans had neither a distinguished scientific tradition nor an adventurous technology. Known engineering principles were often exploited more completely than in the past, as in Roman roads and aqueducts. By far the most advanced technology invented under Roman rule outside of Hellenic centers was the water wheel, but it was not exploited systematically until after the fall of the Western Empire. During this entire period virtually all significant advances in technology were made in China and apparently not communicated to the Romans despite steady trade with the Chinese in various goods.

As many theories have been advanced as to why there are so few classical machines as there are reasons put forward for the fall of the Roman Empire or the demise of the dinosaurs. Unlike the extinction of dinosaurs, whose cause is now becoming clear, the true explanation of the empire's fall or its technological stasis will probably never be known. The later inventors of Antiquity had sufficient means to produce machinery as advanced in concept as that of the early Industrial Revolution. In particular, the somewhat shadowy Heron of Alexandria, probably about the first century CE, described devices that included all the elements needed to build a func-

tional and useful steam engine, either turbine or piston driven. But he used these devices as either toys or as machines priests could install in temples to make it seem that small miracles were taking place. He did not employ them as practical pumps (the first use for piston steam engines in the 18th century) or to power mills or move vehicles. In the 1670s, before truly practical steam engines, Ferdinand Verbiest made a version of Heron's steam turbine (aeolipile). He installed it in a cart and promptly drove the cart a few inches with it. With that in mind, we can boil down the question of why there are no machines to speak of in Antiquity to the even more specific one of why the later Greeks or Romans did not use steam power.

The common reasons put forward include the following:

Slavery Greek and Roman upper classes had an ample supply of barbarian slaves, so they not only did not need steam power, but they also equated anything related to work as definitely lower class and to be avoided.

Poor natural resources The Mediterranean region does not contain large deposits of either coal or iron ore. Indeed, when Marco Polo reported that people in China burned black rocks as fuel, Italians thought he was making things up.

Lack of scientific background Science and technology evolve, just as organisms do. You could no more expect a steam engine before the invention of the thermometer, the microscope, and so forth than you could expect flowering plants before algae, mosses, and ferns.

Lack of technical background Gear-cutting and screw-cutting machines were not devised until the 15th and 16th centuries, when they were used by clock makers. Without metal lathes and similar devices, even the best designed machine would have been impossible to build well enough to function.

Greeks and Romans had other things on their mind

There was a great religious movement for hundreds of years in Hellenic and Roman times, the most likely times for progress on steam engines. People did not care about the material world, only the spiritual one. Evidence for this is that the cleverest devices of the period were devoted to causing temple doors to open mysteriously or to produce other apparently miraculous effects.

■ Construction

Under Claudius, a 60-km (32-mi) aqueduct built to supply Lyon, France, with water includes three inverted siphons, places where the aqueduct descends into a valley and

rises on the far side due to the pressure of the descending water. One siphon consists of 18 lead pipes that cross a ravine 66 m (217 ft) deep on 16-m (52-ft) arches. See also 38 CE CONS; 97 CE CONS.

■ Food & agriculture

Farmers in the Middle East and China begin to store grain in cylindrical, airtight storage bins, similar to modern grain silos. See also 1873 FOOD.

Mary Prophetissa invents the

double boiler, still called the *bain marie* ("Mary's bath") by French cooks.

Σ Mathematics

Sometime before this date, the collection *Jiuzhang suanshu*

("nine chapters on the mathematical art") records the mathematics known to the Chinese in nine chapters that include 246 problems, including methods of measurement, ratio and proportion, constructions, methods for solution of equations and systems of equations, and applications of the Pythagorean theorem. *See also* 263 CE MATH.

⌘ Physics

Quaestiones naturales ("natural questions") by Lucius Annaeus Seneca [b. Spain, c. 4 BCE, d. 65 CE], written about this time, deals with physics, geography, and meteorological phenomena. *See also* 77 CE COMM.

I Tools

Two floating Roman temples are built in Lake Nemi in Italy by Caligula or Claudius sometime between 37 and 59. These contain what appears to be a bilge pump with the first known evidence of a crank handle used for operating it, although hand mills of the time evidently also used handles that were essentially cranks. *See also* 100 BCE TOOL; 300 CE TOOL.

↗ Transportation

The floating temples built on Lake Nemi in Italy contain rotating wooden platforms. One platform is mounted on eight bronze balls with small projections used as axles, the oldest prototypes of ball bearings known, although not strictly ball bearings, since true ones rotate freely. The other is mounted on a similar device using cylinders and stands in the same relation to roller bearings as the other does to ball bearings. *See also* 100 BCE TOOL; 1535 CE TRAN.

52 CE

⌘ Construction

The project to drain Lacus Fucinus is pronounced complete after 11 years and Emperor Claudius attends opening ceremonies on the bank of the Liri River, where the tunnel from the lake is supposed to empty. When the gates are opened, however, no water emerges from the tunnel as a result of an incorrect grade. *See also* 41 CE CONS; 53 CE CONS.

53 CE

⌘ Construction

For the second time Emperor Claudius arranges a ceremony to celebrate the opening of the tunnel dug by crews under Narcissus to drain Lacus Fucinus (Lago Fucino). This time the tunnel is too successful, as the flood of water released when the gates are opened sweeps away the banquet tables. Narcissus is imprisoned and dies shortly afterward. *See also* 52 CE CONS; 1875 CE FOOD.

60 CE

↗ Energy

Heron of Alexandria builds a toy, later called an aeolipile, that uses jets of steam to turn a kettle. As water in the kettle is heated, the steam expands

through vents that make the kettle rotate on an axle. There is apparently no idea of putting the device to practical use. *See also* 600 CE ENER.

Heron describes his invention of a lamp in which a column of saltwater supplies pressure to raise the level of oil into the wick. *See also* 250 BCE ENER; 77 CE ENER.

⌘ Physics

Heron describes experiments with air, including the expansion of air caused by heat. He also writes books about simple machines and about light and mirrors.

Cleomedes [b. first century CE, possibly in Lysimachia, Greece, d. first century CE] calls attention to some of the elementary properties of refraction, such as the bending of a ray of light toward the perpendicular when it passes from a less dense to a more dense medium. There is some evidence that Archimedes and Euclid, both much earlier, may have known that refraction causes a coin in an opaque vase that is just below the line of sight over the rim to become visible when water is poured into the vase. Certainly Cleomedes knew this effect because he correctly notes that the same effect causes the Sun to be visible shortly before it actually reaches the line of sight over the horizon. *See also* 140 CE PHY.

I Tools

Heron describes (and perhaps invents) a device for cutting screws with female threads. Male screw threads still have to be cut by hand. Some of Heron's other devices, not necessarily invented by him, include levels, worm gears, check and float valves (as in flush toilets), a toy windmill, and a force pump and nozzle for use in fighting fires. *See also* 300 BCE TOOL.

↗ Transportation

Nero [b. Antium, December 15, 37 CE, d. Rome, June 9, 68] starts to build a canal across the Isthmus of Corinth, a project contemplated at least as early as 600 BCE, but his increasing political difficulties cause him to abandon it. *See also* 640 BCE TRAN; 1893 CE TRAN.

70 CE

⌘ Construction

Roman emperor Vespasian [b. November 18, 9 CE, d. June 23, 79] orders the building of the Colosseum (originally the amphitheater of Vespasian or the Flavian amphitheater) in Rome. At about 180 m (600 ft) long and 50 m (175 ft) high, it will be the largest amphitheater in the world until the construction of the Yale Bowl in 1914. *See also* 1914 CE CONS.

Heron of Alexandria

[a.k.a. Hero, b. Alexandria, c. 10 CE, d. c. 75]

Heron is thought to have taught at the Museum in Alexandria, and the books that are attributed to him were probably based on lecture notes, as with Aristotle's works. Many of his writings are known in Greek or in Arabic or Latin translations, including *Automaton Making*, *Geometrica*, *Mechanica* (for architects), *Metrica* (on measurement), *Catoptrics* (on mirrors), *Pneumatics* (on mechanical devices worked by air, steam, or water), *Siegecraft*, and *Dioptra* (on the surveyor's transit), as well as a fragment on water clocks and parts of a dictionary of technology. His works survived because of a wealth of practical information on wine presses, cranes, pulleys, and the like. He is best remembered today for a pinwheel that operated by steam, often called the first steam engine. He was also a creative mathematician.

The great eruption of Vesuvius

The classical world of Greece and Rome was well-placed geographically to know about volcanoes. Although not in the Pacific "Ring of Fire," the Mediterranean, stressed by Africa pushing into Europe, is home to a number of volcanoes that were active in classical times, some of which are still active today. The oldest known historical record of a volcano erupting refers to an eruption of Mount Etna in 479 BCE.

Classical mythology explained volcanoes as the work of a god, Vulcan, who lived underground. Vulcan was a blacksmith, and the smoke and fire of the volcano supposedly came from his forge. Vulcan's forge was located on the island of Stromboli, which was almost continuously active in Antiquity.

Greek scientists also tried to explain volcanoes. Aristotle noticed that the volcanoes with which he was familiar were near the sea (actually, most, but not all, volcanoes are near the sea). He suggested that waves on a beach push air into the ground. When that air reaches a mineral that can burn, such as coal or sulfur, the mineral deposits catch fire. These fires then produce volcanoes at Earth's surface.

The Roman people who lived at the base of Mount Vesuvius in late classical times did not recognize that Vesuvius is a volcano (although Strabo identified Vesuvius's volcanic nature about the first decade CE). Even when earthquakes rocked the Bay of Naples, near the mountain, for 15 years, the citizens did not connect the tremors with the mountain. By 79 CE, quakes were becoming frequent.

The coastline at the base of Vesuvius was a popular resort region for Romans. Many had summer homes in the town of Pompeii, nearby at the shore, or on offshore islands. At the very base of the mountain was the town of Herculaneum. When an eruption began on August 24, 79 CE, the area was filled with summer visitors. Also, part of the Roman navy was anchored offshore.

The admiral of this fleet was Pliny the Elder, a well-known naturalist and historian. When the eruption began, he headed toward the volcano out of curiosity. It soon became apparent that his ships were needed for a rescue effort.

It is largely from the accounts of Pliny's nephew, Pliny the Younger, who was also there, that people today know the details of the eruption. Excavations by archaeologists since 1800 have completed the story.

Pompeii was destroyed twice by the eruption. As the residents and visitors were packing their most precious possessions to escape, clouds of poison gas rolled into the city. Those who were out of their houses and not been killed by falling rocks died instantly from the gas. People who were still in their houses died from lack of oxygen.

Pliny the Elder had reached the coast at the town of Stabiae, where a friend needed rescue. By the time Pliny landed, high seas and strong winds prevented his ships from leaving again. As a volcano heats the air around it, the hot air rises very fast. Cooler air rushes toward the volcano, causing strong winds in that direction.

Pliny and his friends waited for the winds to die down, but the falling ash was slowly covering the exits from his friend's house. Escape by sea was impossible, not only because of the winds, but also because the sea level was falling, which sometimes happens during eruptions or earthquakes. The sailors tied pillows to their heads and tried to escape on foot. Pliny, however, was overcome by the poisonous gases from the volcano and died, although others with him survived. The town of Stabiae was totally destroyed.

In the meantime, the second destruction of Pompeii was progressing. As the ash rained down, it gradually covered the entire town, so that only the tops of taller buildings showed above the surface. Rain was also falling, which turned the ash into a kind of cement that completely enclosed the bodies of the dead who were not in houses. The bodies remained so well preserved that today archaeologists are able to make plaster casts that show the expressions and even the clothing the victims wore on their last day on Earth.

The town of Herculaneum, at the base of Vesuvius, was also buried. Volcanic eruptions usually produce large amounts of rain. In this case, the rain was so intense that it caused giant mud slides. One of them buried Herculaneum in 60 feet of mud. Most of the people in the town had left by the time of the mudslide.

Until 1982, it was believed that the people who left Herculaneum had escaped safely. That year, excavations on the beach revealed that many of them had been killed and buried there. The discovery of more than 150 skeletons at the site revealed to physical anthropologists that Roman citizens of the first century were healthy, although somewhat shorter than modern Italians.



POMPEII A wall painting from "the villa of mysteries" illustrates how the volcanic ash from the eruption of Vesuvius preserved intact much of the glory of the old Roman town. The ruins of Pompeii provide striking insights into the everyday life of the early empire, suggesting that archaeology need not be solely concerned with great temples and treasures.

✈ Transportation

Construction of the Grand Canal of China, eventually to be 965 km (600 mi) long and linking the Yangtze and the Huang He (Yellow River), is started. *See also* 133 BCE TRAN; 610 CE TRAN.

77 CE

☛ Communication

Roman scholar Pliny the Elder (Gaius Plinius Secundus) [b. Como, Italy, 23 CE, d. Mt. Vesuvius, August 25, 79] writes his influential *Naturalis historia* ("natural history"), a 37-volume natural history encyclopedia. Containing both accurate and inaccurate observations on nature, scientific facts, and mythology, it will be treated as one of the main reference books in science for the next thousand years. *See also* 630 CE COMM.

☛ Energy

Pliny the Elder mentions that mineral oil (that is, petroleum) found in the Adriatic region is used in lamps there instead of olive oil. *See also* 250 BCE ENER.

🍴 Food & agriculture

Pliny the Elder describes a harvesting machine that, pulled by oxen, cuts off stalks of grain. *See also* 1831 CE FOOD.

☒ Tools

Pliny the Elder describes in detail techniques used in trades of the time. *See also* 50 CE TOOL.

79 CE

❀ Earth science

Pliny the Younger (Gaius Plinius Secundus) [b. Comum, c. 61 CE, d. Bythynia, 111] writes the first detailed account of the eruption of a volcano, that of Vesuvius, which destroys Pompeii and Herculaneum and also kills his uncle, Pliny the Elder. *See also* 4803 BCE EAR.

❖ Materials

Wire cable is being made by this time as we know from a 5-m (15-ft) length of 2-cm (1-in.) bronze cable found in the ruins of Pompeii, destroyed by Vesuvius this year.

83 CE

☒ Tools

Lun héng ("disquisitions, or balanced inquiries") by Wang Ch'ung [b. China, 27 CE, d. 100] mentions a south-controlling spoon made from lodestone that points south when placed on a polished bronze plate. Although this is clearly a compass, it is used only for divination at the time. The handle of the spoon points north-south. *See also* 300 BCE MATR; 271 CE TOOL.

Wang Ch'ung's *Lun héng* gives the first known reference to the chain pump, a method of raising water from rivers or lakes.

84 CE

★ Astronomy

Chinese astronomers Fu An and Chis Kuea improve on the armillary ring for locating stars by combining a ring that shows the equator with one

that shows the Sun's motion through the sky (the ecliptic).

90 CE

🍴 Food & agriculture

The Chinese invent a device that winnows grain using a rotating fan to separate the grain from the chaff. *See also* 100 CE FOOD.

97 CE

☒ Construction

A two-volume work on Roman aqueducts, *De aquis urbis Romae*, by Roman soldier and administrator Sextus Julius Frontinus [b. c. 30 CE, d. c. 104] summarizes major advances in construction since ancient times. *See also* 50 CE CONS; 109 CE CONS.

100 CE

Ĝ Archaeology

The Moche (Mochica) people of Peru experience a period of cultural expansion starting about this time, featuring giant pyramids, the rediscovery of lost-wax casting, and some of the most realistic pottery of the ancient world. *See also* 500 BCE CONS.



Ĝ Chemistry

Pseudo-Democritus (that is, a writer claiming falsely to be the much earlier Greek philosopher Democritus) writes *Physica et mystica*, the earliest known work on alchemy. *See also* 400 CE CHEM.

☒ Construction

Roman emperor Trajan [b. near Seville, Spain, September 18, 52 CE, d. Selinus, Cilicia, August 9, 117] reduces the limit on height for buildings in Rome to about 18 m (60 ft) for greater safety. *See also* 15 BCE CONS.

Roman engineers learn shortly before this date how to use an ordinary round dome (not a cloister vault) to roof a square building. They insert slanting triangles, called pendentives, at the corners of the square to provide a connection between the circular dome and the square walls. This method becomes an important feature of Byzantine architecture. *See also* 100 BCE CONS.

Roman engineers learn shortly before this date that two cylindrical vaults (essentially extended arches) can cross each other at right angles, creating a roof that can cover a large square.

MOCHE POT Several civilizations preceded the Inca in South America. The Moche are especially known for their realistic portraits in ceramics, including depictions of disease or everyday activities. Here the pot shows a man in traditional garb carrying several pots himself.

Such cross vaults or groined vaults become common in both Roman and later medieval architecture. *See also* 200 CE CONS.

The city of Teotihuacán is laid out in a rectangular grid centered on a 6.4-km (4-mi) boulevard known today as the Avenue of the Dead. The entire city covers 20 sq km (8 sq mi), about the same size as contemporary Rome. It is eventually flanked by two enormous pyramids. The one known today as the Pyramid of the Sun is built first and covers about the same area at its base as the Great Pyramid of Khufu (Cheops). The Pyramid of the Moon, built centuries later, is only slightly smaller. *See also* 500 BCE CONS.

II Food & agriculture

The Chinese discover that dried, powdered chrysanthemum flowers can be used to kill insects. This is believed to be the first insecticide. The active ingredient, pyrethrum, is widely used today, especially on growing vegetables, since it is biodegradable and virtually harmless to mammals. *See also* 600 BCE FOOD.

The Chinese invent the multi-tube seed drill. *See also* 1500 BCE FOOD.

Horticultural writer Columella (a.k.a. Lucius Junius Moderatus Columella), in *De re rustica* (“country matters”), suggests the first known cold frames, glass (or transparent gypsum or mica) boxes in which to raise or grow plants sensitive to cold. He recommends putting them on wheels to roll outside on sunny days.

◆ Materials

Glass windowpanes of the modern type appear in houses of the early Roman Empire. *See also* 100 BCE MATR.

According to second-century Roman author Pausinius, “Theodorus of Samos [is] the first to discover how to pour or melt iron and make statues of it”; that is, he re-discovers cast iron. *See also* 31 CE TOOL; 300 CE MATR.

Copper is in use in the Americas. Copper metallurgy is well-developed by the Moche in Peru (200 to 600 CE), so its use may have started even earlier. *See also* 2500 BCE MATR; 500 CE MATR.

Σ Mathematics

Spherics, by Menelaus of Alexandria [b. Alexandria, c. 70 CE, d. c. 130] written about this time, establishes spherical trigonometry. *See also* 100 BCE MATH; 510 CE MATH.

Nichomachus of Gerasa’s *Introductio arithmeticæ*, written about this time, summarizes the existing knowledge of number theory, including listing the only four known perfect numbers: 6, 28, 496, and 8128 (a number is perfect if the sum of its factors is the number, as $1 + 2 + 3 = 6$ and $1 + 2 + 4 + 7 + 14 = 28$). *See also* 300 BCE MATH.

I Tools

The double-armed catapult, rather like a large crossbow, is replaced by the single-armed catapult, more like a torsion-propelled spear thrower than like a bow. The new catapult is nicknamed the onager after the Asiatic wild ass, an animal that, legend has it, defends itself by kicking stones at pur-

suers. *See also* 332 BCE TOOL; 1100 CE TOOL.

The Chinese invent methods for drilling deep wells to obtain salt water and natural gas. Their method uses ropes so that a person does not have to travel to the bottom of the well to dig it. The drill bit is a heavy pointed weight attached by ropes to a rocking bar at the top of the well. The rocker is used to raise and drop the bit repeatedly. Large bamboo derricks are used to raise and lower the cast-iron drill bits. The methods, with improvements, will be used for the next thousand years at least. Eventually the wells will reach 1460 m (4800 ft). *See also* 100 BCE ENER; 347 CE ENER.

✈ Transportation

The Roman emperor Trajan, like Ptolemy II almost 400 years earlier, restores the canal begun by Pharaoh Necho II about 600 BCE and completed a hundred years later by Darius the Persian. Unless constantly dredged, the canal soon fills up with blown sand. *See also* 280 BCE TRAN; 640 CE TRAN.

The Chinese discover that horses can be hitched with one horse in front of another, allowing a heavier load without need for a wider road. The tandem hitch spreads through Europe in the Middle Ages. *See also* 110 BCE TRAN.

The Greek merchant Alexander reaches the south of China by sea.

There is some evidence that horseback riders in India are using toe stirrups about this time — the toe is inserted in a loop hung from each side of the saddle in the manner of a modern foot stirrup. *See also* 302 CE TRAN.

105 CE

■ Construction

Apollodoros of Damascus [b. c. 50 CE, d. c. 130] builds a famous bridge across the Danube for Roman Emperor Trajan to use in conquering the Dacians (who live in what is now Romania). The depiction of it on the column Trajan erected to commemorate this victory shows that the bridge used a truss, or diagonal, load-bearing member. In time, the truss becomes the foundation of construction, especially in the 19th century, but this is the first recorded use.

◆ Materials

Chinese tradition has it that paper is invented by the eunuch Tsai Lun [b. Kueiyand, Kweichow, China, c. 50 CE, d. c. 118]. However, archaeological evidence suggests that paper was invented at least 250 years earlier, although used for packing and other purposes, not for writing upon. *See also* 140 BCE MATR; 110 CE MATR.



BRIDGE FROM TRAJAN'S COLUMN

Trajan's column in Rome has carved on it the history of his campaign against the Dacians, a campaign that included building a bridge for his army to cross. To historians of technology, the carving of the bridge is famous because it demonstrates that the Romans knew how to use triangular trusses to provide support for a roadway.

109 CE**Construction**

The 57.3-km- (35.4-mi-) long Aqua Trajana carries water underground to Rome. It is the tenth major aqueduct in Rome's water supply. *See also* 38 CE CONS; 226 CE CONS.

110 CE**Materials**

The oldest known piece of paper used for writing dates from this year. *See also* 105 CE MATR; 589 CE MATR.

115 CE**Construction**

Roman emperor Hadrian [b. Spain, January 24, 76 CE, d. near Naples, July 138] builds a 24-km- (15-mi-) long aqueduct to supply Athens. It is still in use today, although supplemented by a new system built between 1920 and 1931. *See also* 226 CE CONS.

116 CE**Communication**

Zhang Heng develops the method of using a grid to locate points on a map. *See also* 300 BCE EAR.

117 CE**Astronomy**

Zhang Heng creates an armillary sphere, a model of the universe with rings that represent the main features of the universe. Gears connect the inner and outer spheres so that each heavenly body moves in its proper relationship with the others. *See also* 84 CE AST; 125 CE AST.

Zhang Heng

[a.k.a. Pingshi or Chang Heng, b. Shiqiao Nan Yang, China, 78 CE, d. 139]

Like many of the early Greek philosophers, Zhang began his career with extensive travel. In 111 CE he took a government post in charge of recording astronomical phenomena, forecasting weather, and compiling calendars. Based on this experience he wrote *Lingxian*, a summary of Chinese astronomical knowledge, including explanations of eclipses, the best star map to date, and various observational data. But he is most famous in the West for his invention of the first seismograph. He is also known as a mathematician who proposed the square root of 10 (about 3.1623) for π . In addition, he was a poet and some say a painter of great skill.

with the seasons. *See also* 46 BCE AST.

125 CE**Astronomy**

Zhang Heng adds a third ring to the armillary, bringing it to its fully developed form. *See also* 117 CE AST.

126 CE**Construction**

Roman emperor Hadrian builds the Pantheon, a magnificent domed building honoring seven gods; it still stands. In addition to its remarkable dome, it also uses a bronze truss, but that was removed and melted down for cannon in 1625. *See also* 105 CE CONS; 1570 CE CONS.

mais Hermae (Acre, Israel), c. 85 CE, d. c. 165] writes *Syntaxis mathematica* ("mathematical collection"), best known by its Arabic name, *Almagest*, about this time. It becomes the most important text on astronomy during the Middle Ages. In it, Ptolemy catalogs constellations, stars, and nebulae visible to the naked eye and provides a description of how planets move based on circles and epicycles of motion about a fixed Earth. *See also* 350 BCE AST; 1543 CE AST.

Earth science

Ptolemy's *Geographia* ("geography"), written about this time, includes an atlas of the known world based on the travels of Roman legions. *See also* 20 CE EAR.

120 CE**Tools**

A reference to "brazen pipes blown from below . . . by bellows" in Pollux' *Onomasticon* is considered to be the first mention of a pipe organ, although the water organ, its ancestor, goes back to the time of Ctesibius and Heron of Athens. *See also* 200 BCE COMM.

132 CE**Astronomy**

Zhang Heng combines a water clock with an armillary to produce a device that, somewhat like the modern planetarium, keeps track of where stars are expected to be in the sky. *See also* 1075 CE TOOL.

Earth science

Zhang Heng invents the world's first seismograph, a device that indicates the direction of an earthquake by dropping a ball from the mouth of a bronze dragon into the mouth of a bronze frog. *See also* 1900 CE EAR.

Physics

In his *Optics* Ptolemy includes the earliest surviving table of the angles of incidence for refraction from air to water. Often called the most remarkable experimental research of Antiquity, the table, with probably the exception of the 40.5 degrees for the refraction angle for an angle of incidence of 60 degrees, is actually computed according to an arithmetic series of the second order (essentially a quadratic function) and is not especially close to measured values. *See also* 40 BCE PHY.

122 CE**Construction**

Roman engineers and soldiers build Hadrian's Wall to protect Britain from northern tribes. *See also* 214 BCE CONS.

123 CE**Astronomy**

Zhang Heng corrects the Chinese calendar so that it agrees

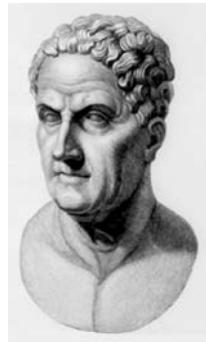
140 CE**Astronomy**

Ptolemy (Claudius Ptolemaeus) [b. possibly at Ptole-

166 CE**Transportation**

What is probably the first actual contact between Roman and Chinese emissaries occurs, although they have been trading indirectly

for a couple of hundred years along the Silk Road. The emissaries that reach the Han court claim to come from Andun, king of Da Qin, according to Chinese chronicles, but other evidence suggests that they are representing the Roman emperor Marcus Aurelius Antoninus. *See also* 53 BCE MATR.



Galen (Claudius Galen) of Pergamum

[b. Pergamum (Turkey), c. 131 CE, d. Sicily(?), c. 201]

Many of Galen's writings in clear Attic Greek survive, making him the major influence on European medicine until the Renaissance. His primary contribution was to have carefully dissected and observed many mammals, including Barbary apes but apparently not including humans, and to have accurately (for the most part) described such structures as the nervous system, the heart, the kidneys, and so forth. His philosophical bent was that God has designed living creatures to function perfectly and that study of these creatures reveals God's purpose. Although Galen was more Stoic than Christian, this attitude helped maintain the popularity of his works throughout the Christian world of the Middle Ages. For the next 1400 years, Galen's ideas — many correct, others incorrect — were considered infallible.

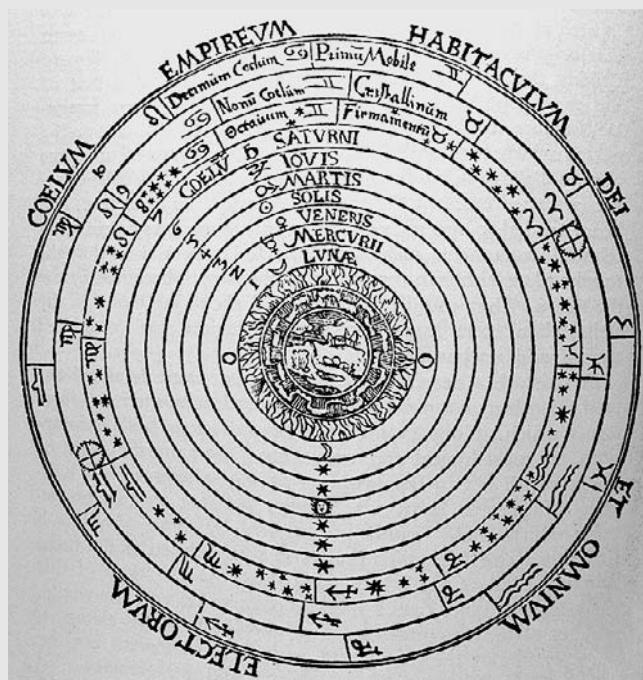
The *Almagest*

Ptolemy was the last great astronomer of the Alexandrian school in Egypt. He also was a prolific writer in science, best known for his book, the *Almagest*.

He wrote the *Almagest*, originally named *Syntaxis mathematica* ("mathematical collection"), during the second century CE. The Arabs were so taken with this book that they began to call it *Al magiste* ("the greatest"), later corrupted to *Almagest*. The book is a full description of all that was known in astronomy around Ptolemy's time and is a synthesis of Ptolemy's ideas and of those of other Greek scholars, such as Aristotle, Pythagoras, Apollonius of Perga, and Hipparchus. These scholars believed that Earth is the center of the universe. Ptolemy also included a catalog of stars compiled by Hipparchus in 130 BCE.

The most important part of the *Almagest* is its description of the Ptolemaic system, a model of planetary motion in which Earth is the center of the universe and the Sun and Moon move around Earth in perfect circles. Because the planets seem to move backward some of the time, however, their observed motion cannot be explained by single circles. Ptolemy adopted a solution to this problem that he attributes to Apollonius (although earlier Greek writers, such as Hipparchus, also used this concept): Each planet moves on a small circle, called an epicycle. The epicycle has as its center a point called the deferent, and the deferent itself moves on a perfect circle around Earth. As seen from Earth, the planet moves faster when its path about the deferent is advancing and, because the orbit about the deferent takes less time than the orbit about Earth, the planet first slows and then moves backward on the other half of the trip around the deferent. Although these complex

motions seem strange to those familiar with modern astronomy, they succeed in accounting for observed motions.



PTOLEMAIC UNIVERSE The large object at the center of the concentric spheres in the Ptolemaic universe was Earth. It was clear to ancient astronomers that the Moon (*Luna*) orbits Earth and that both Mercury and Venus are between Earth and the Sun (*Solis*). They also knew from the planets' speeds that Mars is closer than Jupiter (*Jovis*), which is closer than Saturn. The fixed stars are shown beyond Saturn. The major error, however, was placing the Sun between Venus and Mars (a location we now know to be occupied by Earth).

170 CE**♥ Medicine & health**

Galen of Pergamum is the first to take a person's pulse and use it in diagnosing problems. He shows that arteries contain blood, not air as had been believed. Galen describes the anatomy of the brain and its ventricles, demonstrating that different parts of the spinal cord control different muscles and that severing the spinal cord results in disabling voluntary motions of the part of the body below the cut. *See also* 260 BCE MED.

175 CE**⊕ Earth science**

Pausanias [b. Greece, c. 115 CE, d. c. 180] describes the discovery of what he believes to be bones of the hero Ajax, who fought in the Trojan War. The bones probably were from a fossil mastodon or rhinoceros. Ancient accounts often explain fossils as remains of giants or monsters. *See also* 350 BCE EAR; 1250 EAR.

185 CE**★ Astronomy**

The Chinese observe a "guest star," most likely a supernova, in the constellation Centaurus, which remains visible for 20 months. *See also* 386 CE AST.

189 CE**I Tools**

In China, Ting Huan, who is believed to be the inventor of a form of magic lantern, reinvents a cardan suspension, or gimbals, to use with an incense burner. Earlier records report

that another Chinese inventor, Fang Feng, had invented a similar device c. 140 BCE, but his methods had been lost until Ting Huan's re-creation. *See also* 140 BCE TOOL.

190 CE**⌚ Communication**

According to carbon-14 dates, the Nazca lines and figures, giant drawings on the pavement of the world's driest desert (Peru) that include various animals, spirals, and geometric figures, all clearly visible only from airplanes, are made starting at this time. Creation of the lines appears to have continued until about 600.

199 CE**⌚ Communication**

October 9 of this year is the first recorded date of a specific event in Maya history. *See also* 36 BCE COMM.

200 CE**⌚ Communication**

The Zapotec of Monte Albán (near Oaxaca, Mexico) develop the crude pictographic writing of their Olmec predecessors into a full-fledged hieroglyphic script that is used to record mostly dates and events. *See also* 200 BCE ARCH.

■ Construction

The Maya center at Tikal, built about this time, has shrines at the peaks of pyramids that are roofed with corbel arches, the only arches of any kind known in the Americas. *See also* 100 CE CONS.

At Moche, the apparent capital of the Moche (Mochica)

civilization of coastal Peru, two huge adobe structures are built. The Huaca del Sol is a terraced platform 2400 by 160 m (1120 by 530 ft) at the base and 41 m (135 ft) high, built from about 130,000,000 mold-made adobe bricks. The Huaca de la Luna is on a platform about half that size and is a terraced complex of many separate rooms decorated with painted murals. *See also* 100 CE ARCH.

🍴 Food & agriculture

The Chinese invent the whiffle-tree (a.k.a. whippletree), a device that allows two oxen to pull a single cart together. It is a bar attached by a swivel to the front of the cart — the oxen are harnessed to the bar. It is reinvented in the West in the eleventh century for use with horses. *See also* 100 CE FOOD.

⊕ Materials

The Chinese develop improved ceramic techniques, a step toward the first production of porcelain, perhaps 600 years later. *See also* 800 CE MATR.

Σ Mathematics

Chinese mathematicians are using powers of ten to express numbers, and also red counters to represent positive numbers and black counters to represent negative numbers. *See also* 250 CE MATH.

226 CE**■ Construction**

The 22.2-km- (13.7-mi-) long Aqua Alexandrina aqueduct is the eleventh and last of the major aqueducts serving ancient Rome, a water-supply system that began in 312 BCE with the underground Appia. The Aqua Alexandrina is

built almost entirely on arches. The complete aqueduct system is able to supply about 120,000,000 to 320,000,000 liters (30,000,000 to 80,000,000 gal) of water to the city during each 24-hour period. *See also* 109 CE CONS.

250 CE**⊕ Materials**

Parchment supersedes papyrus as writing material for the first time in the lands around the Mediterranean. *See also* 2500 BCE MATR.

Σ Mathematics

Arithmetica, written by Diophantus [b. Greece, c. 210 CE, d. c. 290] about this time, is the earliest treatise known that is devoted to what we now call algebra. It is a collection of problems that involves solutions in the counting numbers, or positive integers, only. In consequence, equations with these restrictions are now called Diophantine equations. The reason this work is considered algebraic is that Diophantus introduces the use of symbols, such as a letter in the Greek alphabet as a variable (most likely a form of delta) and designators for powers, such as squares, cubes, and fourth powers. He also uses symbols for subtraction and equality.

Diophantus obtains negative numbers as solutions to equations, but dismisses them as "absurd." *See also* 200 BCE MATH.

260 CE**→ Transportation**

In China, scholar Ma Chün builds a "south-pointing carriage" using differential gears.

The *Sung shu* written about 500 CE reports that Ma Chün was ordered by the emperor to duplicate the legendary carriage said to have been produced 1200 years earlier by the Duke of Chou. This was not the first attempt to re-create the south-pointing carriage, but apparently that of Ma Chün worked reasonably well. It did need some human assistance to keep it aligned on rough ground. *See also* 1050 BCE TRAN.

263 CE

Σ Mathematics

Chinese mathematician Liu Hui writes a commentary on the *Jiuzhang suanshu* (“nine problems”). In it he uses polygons of up to 3072 sides to calculate π to 3.14159. He provides a proof of the Pythagorean theorem and calculates the volume of a sphere, cylinder, and similar solids using an idea similar to the concept of a limit. *See also* 50 CE MATH; 460 CE MATH.

269 CE

↳ Communication

A series of wars and revolts are thought to result in partial destruction of the Library at Alexandria. The first of these occurs when Septima Zenobia, queen of Palmyra, captures Egypt. *See also* 40 BCE COMM; 272 CE COMM.

271 CE

I Tools

In China, the first form of a compass is probably in use for finding south. Earlier applications of magnetic lodestones were more magical than prac-

tical. *See also* 83 CE TOOL; 1044 CE TRAN.

272 CE

↳ Communication

Roman emperor Aurelian [b. c. 215 CE, d. 275] puts down a revolt in Alexandria and probably destroys part of the Library. *See also* 269 CE COMM; 295 CE COMM.

295 CE

↳ Communication

Roman emperor Diocletian puts down yet another revolt in Alexandria and probably destroys part of the Library. *See also* 272 CE COMM; 391 CE COMM.

300 CE

★ Astronomy

Chinese astronomer Chen Zhuo combines the star maps produced by Shih Shen, Gan De, and Wu Xien in the fourth century BCE into a single map. *See also* 150 BCE AST.

The Maya develop the day-count calendar, which combines the 365-day Olmec calendar that has a 52-year cycle with the 260-day cycle known as the tzolk'in, which has 13 cycles of 20 days each. This is used to date events back to 3000 BCE (the earlier events are thought to have been legends or myths). *See also* 200 CE CONS.

▷ Chemistry

The Greek alchemist Zosimos of Panopolis summarizes the available work of hundreds of Egyptian alchemists. Although most of his book is pure mysticism, he describes what is

apparently arsenic and lead acetate, both for the first time. About this time also, Roman emperor Diocletian orders destruction of alchemical books and manuscripts for fear that success in making gold from base metals would debase the currency. *See also* 100 CE CHEM; 400 CE CHEM.

↳ Communication

Extrapolation from later developments suggests that the Maya are beginning to develop written books. *See also* 600 CE COMM.

¶ Construction

The palace of Diocletian at Spalatum (Split, Croatia), built about this time, uses arches supported by free-standing columns, a device that becomes common in medieval architecture. *See also* 100 CE CONS.

◊ Materials

By this time bellows are in use in Europe to produce higher quality iron. Bellows had been producing cast iron in China for about 600 years and had been used in the Near East as early as 1600 BCE. *See also* 31 CE TOOL.

The earliest known knitted fabrics date from about this time, although net-making, the ancestor of knitting, seems to go back to Neolithic times. *See also* 7500 BCE MATR.

The Chinese learn to use coal instead of wood as the fuel in making cast iron. *See also* 1611 CE MATR.

Σ Mathematics

About this time the Chinese may have begun to develop the abacus, although the first printed reference to one

comes in 1593 CE. *See also* 500 CE MATH.

302 CE

→ Transportation

In China the earliest known depiction of a stirrup is made. It is a mounting stirrup, on one side of the saddle, rather than a pair of riding stirrups. *See also* 100 CE TRAN; 477 CE TRAN.

304 CE

॥ Food & agriculture

The first recorded example of biological control of pests is made in China as part of Hsi Han's *Record of Plants and Trees of the Southern Regions*. He reports on how specially selected ants are used to protect mandarin oranges from other insects that might attack the plants. *See also* 100 CE FOOD.

320 CE

Σ Mathematics

Synagoge, a.k.a. the *Mathematical Collection*, by Pappus of Alexandria [b. Alexandria, Egypt, c. 290 CE, d. c. 350], written about this time, summarizes the geometric knowledge of the time and also includes a few ingenious proofs owed to Pappus himself. The book is the best account we have of various missing books of earlier Hellenistic mathematicians, such as Euclid and Apollonius, as well as the only source for others, such as Erycinus. Pappus's work on the loci of points with respect to several lines will inspire the creation of analytic geometry. *See also* 300 BCE MATH.

327 CE**Construction**

At Antioch (Turkey), Emperor Constantine [b. c. 280 CE, d. May 22, 337] orders an octagonal church with the altar and pulpit in the middle and aisles radiating from the altar like spokes. The church, the Domus Aurea, sets the style for such central Romanesque churches for the next few centuries. *See also* 126 CE CONS.

330 CE**Archaeology**

On May 11 — a date deemed propitious by astrologers — the new city that will come to be known as Constantinople (Istanbul, Turkey) is dedicated, after having been laid out by Roman emperor Constantine as the new capital of the Roman Empire.

338 CE**Construction**

Emperor Constantine of Rome repairs the Aqua Virgo aqueduct. *See also* 537 CONS.

347 CE**Energy**

Zhang Zhu describes the use by the Chinese of methane gas, obtained from boreholes in the ground and transported through tarred bamboo pipes and burned to light towns. *See also* 1 BCE TOOL.

350 CE**Energy**

The city of Antioch (Turkey) installs the world's first system

of public lighting. *See also* 1812 CE ENER.

Tools

The physician Oribasius [b. c. 325 CE, d. c. 403] mentions the use of cranks as a device helpful in setting broken bones, the first known mention of a crank in Western writings. Some have thought that this mention implies that cranks were in regular use for such torture instruments as the rack. *See also* 50 CE TOOL; 830 CE TOOL.

369 CE**Astronomy**

Chinese astronomers report a new star (possibly a supernova) that remains visible for five months. *See also* 185 CE AST; 386 CE AST.

370 CE**Transportation**

A Roman writer known as Anonymous who addresses military matters suggests to the Emperor that warships be built with three pairs of paddle wheels, each wheel powered by oxen walking capstan spokes about the deck. Within the next 200 years such boats are actually in use. *See also* 520 CE TRAN.

373 CE**Communication**

Roman emperor Valens orders the burning of all non-Christian books. *See also* 391 CE COMM.

375 CE**Tools**

Verses by Decimus Magnus

Ausonius [b. Gaul, c. 310 CE, d. Gaul, c. 395] written in Gaul (northern Europe) refer to a water-powered sawmill, the earliest evidence known that waterpower had been applied to sawing lumber. *See also* 25 BCE ENER.

386 CE**Astronomy**

Chinese astronomers report a new star (possibly a nova) that remains visible for three months. *See also* 369 CE AST; 390 CE AST.

390 CE**Astronomy**

Chinese astronomers observe a "guest star," most likely a supernova, in the constellation Scorpio; it remains visible for eight months. *See also* 386 CE AST; 1006 CE AST.

391 CE**Communication**

The final destruction of the Library at Alexandria is often attributed to a Christian mob led by Bishop Theophilus in this year; but other sources say that the mob simply burned the Temple of Serapis, where some of the books were kept. *See also* 295 CE COMM; 646 CE COMM.

400 CE**Chemistry**

The term *chemistry* is used for the first time by Alexandrian scholars for the activity of changing matter. *See also* 300 CE CHEM.



GIANT SANDSTONE BUDDHA Seen here before the statue was blown up by Islamic fundamentalists, who object to any depiction of images from life, this Buddha is typical of the Asian practice of carving statues out of living rock — although this particular Buddha was much larger than any others.

Construction

The Buddhist monastery Bamiyan is carved into the sandstone cliffs of the foothills of the Hindu Kush (Afghanistan), housing 1000 monks and a 37-m- (120-ft-) high statue of Buddha. The giant statue and another of Buddha will be demolished by the Afghan government, run by a group called the Taliban, in March 2001. *See also* 489 CE ARCH.

The early Anasazi people enter what is now called the four corners region (where Colorado, Utah, Arizona, and New Mexico come together at right angles). They are hunter-gatherers, living in caves along rocky cliffs and canyon walls. *See also* 500 CE CONS.

Energy

The overshot water wheel, in which water that has been retained in a mill pond is

directed by means of a chute over the top, is developed in the Roman Empire (although it probably originated about 200 years earlier). By controlling the level of the pond feeding the water with sluices, the water mill can function most of the year and be operated only when needed for grinding grain or extracting oil from olives. *See also* 25 BCE ENER.

❖ Materials

About this time the Chinese learn how to make steel by forging together cast and wrought iron. *See also* 500 BCE MATR.

Σ Mathematics

Theon and Hypatia of Alexandria prepare editions of Euclid's *Elements* and his *Optics*.

I Tools

Hypatia of Alexandria develops the hydroscope (also called hydrometer), an instrument for determining the specific gravity of a liquid. It consists of a sealed tube weighted at one end. The depth the tube sinks into a liquid is the measure for its specific gravity. She also improves the astrolabe. *See also* 200 BCE AST.

The Chinese invent the umbrella. *See also* 1 CE TRAN.

405 CE

↳ Communication

The arrival of the Chinese scribe Wani to teach the Japanese crown princes to read and write signals the official adoption of Chinese ideograms as the way to write in Japanese.

415 CE

❖ Materials

About this time a 7-m (24-ft) pillar of iron is erected at Delhi, India, as the base of a statue. Although the statue is long gone, the pillar remains, largely as a result of the extreme purity of the iron. Iron chains are regularly used in suspension bridges in India as well. *See also* 1 CE CONS.

450 CE

Σ Mathematics

Neoplatonic philosopher Proclus [b. Constantinople (Istanbul, Turkey), February 8, 411 CE, d. Athens, Greece, April 17, 485] writes *In Primum Euclidis Elementorum Librum Comentarii* ("commentary on Euclid's *Elements*"), the prin-

cipal source of information about early Greek geometry. Proclus is credited with a postulate equivalent to Euclid's fifth postulate and known today as Playfair's postulate after a 19th-century rediscovery by John Playfair. It states that through a given point only one line parallel to a given line can be drawn. *See also* 300 BCE MATH; 880 CE MATH.

460 CE

Σ Mathematics

Chinese mathematician Tsu Ch'ung-Chih (aka Zu Chongzhi) [b. 429 CE, d. 500] and his son Tsu Keng-Chih (aka Zu Gengshu) calculate π as 3.1415929203 by the method of polygons, using a circle 10 feet across (the correct value to the same number of decimal places is 3.1415926535). *See also* 200 CE MATH; 635 MATH.

477 CE

↗ Transportation

Archaeological evidence suggests that the use of a pair of stirrups for mounting horses and stability while riding is invented in China or Korea about this time. *See also* 302 CE TRAN.

489 CE

❖ Archaeology

Giant statues of Buddha, some 50 m (160 ft) tall, are chiseled from rock cliffs at Yungang (Datong, Shanxi Province, China). *See also* 400 CE CONS; 494 CE ARCH.

494 CE

❖ Archaeology

After the capital of the Wei empire in China is returned to Luoyang (Henan Province, China) — where the capital had been until Luoyang was sacked by the Huns in 311 — Buddhist monks move the project of carving statues of Buddha in river cliffs from Yungang to Longmen, 12 km (8 mi) south of Luoyang. There over a period of about 300 years they carve from 100,000 to 150,000 statues into the rock. *See also* 489 CE ARCH.

500 CE

❖ Construction

After the Anasazi occupy the "four corners" region, they begin to make their first true houses, domes of logs plastered with mud laid horizontally around a saucerlike excavation. *See also* 400 CE CONS.

Because of an increase in rainfall at this time in Europe, low-lying regions, such as what is now the Netherlands, begin to flood; where before people lived and farmed on "islands" in swamps, water rising as much as 10 cm (4 in.) per century causes people to build dikes around their "islands" to maintain their land. Gradually this process leads to diking and draining swamps to make new arable land.

The Mogollon people (New Mexico) make pit houses, with living areas sunk a meter or two (3 to 5 ft) below grade and the single room covered over with a sloping roof of mud-coated branches and

thatch supported by timbers. *See also* 400 CE CONS.

🍴 Food & agriculture

Chinese farmers of this time already employ practices such as planting crops in rows, hoeing weeds, and using manure from farm animals as fertilizer on crops. Such advances will not be used in the West until the 18th century.

❖ Materials

About this time Iranian monks smuggle domesticated silkworm eggs from China to Constantinople, reviving a western tradition of silk manufacture that had languished since classical times because the cocoons of the wild silkworm moths did not yield very good fiber. But most silk continues to be imported from China, even though local cultivation continues after this time. *See also* 53 BCE MATR; 1260 CE MATR.

People in South America, notably the Manteño culture (Ecuador), manufacture thin copper axe heads that apparently are used as a form of money up and down the west coast of the Americas (some are found as far north as Mexico). The axes are too thin to be used as tools or weapons. *See also* 100 CE MATR.

Σ Mathematics

The abacus is used in Europe,

although counting boards based on the same principle had been used by the ancient Greeks and Romans as much as a thousand years earlier. *See also* 300 CE MATH.

I Tools

The most elaborate water clock ever constructed in the West is built at Gaza near the frontier between Egypt and Palestine (Israel). As a statue of Helios moves below a series of doors to mark the time, the hours are indicated by other statues beating gongs and popping from open doors. At day's end, a mechanical trumpet blows. *See also* 132 CE AST.

✈ Transportation

Polynesian sailors reach Easter Island, the most remote island that they colonize. *See also* 200 BCE TRAN.

510 CE

★ Astronomy

Aryabhata I [b. India, 476 CE, d. India, 550] writes the *Aryabhatiya*. In it he recalculates Greek measurements of the solar system, obtaining a nearly correct value for Earth's circumference. Although he mostly accepts Ptolemy's scheme of the universe, he also puts forward the idea that Earth rotates and that the orbits of the planets are ellipses. He

believes that the Moon and planets shine by reflected sunlight and gives correct explanations for eclipses. *See also* 240 BCE EAR.

Σ Mathematics

Aryabhata, in the *Aryabhatiya*, includes a good value of 3.1416 for the ratio of a circle's circumference to its diameter and uses the decimal and place-value numeration system. His book also contains a variety of rules for algebra and for plane and spherical trigonometry, not all of them correct. Aryabhata also solves some Diophantine equations. *See also* 250 CE MATH.

Eutocius [b. Palestine, c. 480 CE, d. c. 540] writes the first of three commentaries on the works of Archimedes and one on the works of Apollonius. These remain the best source to this day of some of their mathematics.

517 CE

❀ Physics

Experiments on freely falling bodies are conducted by Ioannes Philoponus of Alexandria. *See also* 1586 PHY.

520 CE

✈ Transportation

The author known as Anony-

mous Byzantinus ("the unknown from Byzantium") describes in his book *De re bellicus* ("on things of war") a paddle-wheel warship powered by oxen walking in circles, as mills are sometimes powered. *See also* 370 CE TRAN.

525 CE

★ Astronomy

Roman monk Dionysius Exiguus [d. c. 545 CE] introduces a calendar based on his calculations of the birth of Jesus Christ. Due to an error, he is at least four years off (Jesus must have been born by at least 4 BCE since the Bible says Herod is king of Israel). Also, since zero was not recognized as a number, his calendar goes directly from 1 BCE to 1 CE, as we label them today, a convention still maintained. *See also* 46 BCE AST; 1582 CE AST.

529 CE

Σ Mathematics

The Academy and the Lyceum, the schools started by Plato and Aristotle at Athens, are closed by the Christian emperor Justinian, who believes that the schools teach pagan beliefs. *See also* 387 BCE PHY.



Medieval Science and Technology: 530 through 1452

With the disappearance of the last great centers of learning from Antiquity — the Academy and Lyceum in Athens were closed down by the Byzantine emperor Justinian in 529 and the Museum of Alexandria, only a shadow of its former self, was destroyed by the Arabs in 641 — scientific activity almost ceased in the Western world. Although there was a revival among church scholars in the twelfth century this was snuffed out in the general disarray following the Black Death in the 14th century. A true revival of Western science can be dated from the middle of the 15th century, when the fall of Constantinople to the Turks resulted in scholars bringing many Greek manuscripts into Europe in 1453. Printing also began about this time, changing the way that scientific ideas could be communicated. Thus, we use 530 and 1452 as the boundary dates for this period.

The decline of science in Europe

The fall of the Roman Empire was followed by the extinction of the administrative and military infrastructure that had been established throughout western Europe by the Romans. Roads, bridges, and water-supply systems built by the Romans fell into disrepair, postal services ceased, the use of currency became replaced by barter, and agricultural production diminished considerably. Trade almost ceased entirely, and people relied on the local production of food and goods. During the first centuries after the fall of the Roman Empire the standard of living in Europe returned to levels comparable to those

just after the Agricultural Revolution. Poverty was endemic and people suffered from wars, piracy, famine, and epidemics. Inevitably, science retreated as well.

Several reasons for the decline of science in Europe between 530 and 1000 have been put forward by historians. For one, the Romans had been notoriously little interested in theoretical science; most advances during Roman times had been made in the Hellenistic region that had fallen under Roman domination. When the Roman Empire split in half in 395 CE, the Eastern Empire, centered at Byzantium, later rechristened Constantinople (Istanbul, Turkey), became more like the older Roman Empire with respect to science than like the former Hellenistic region that it encompassed. There are no large advances in theoretical science from Byzantium and only a few technological improvements.

Christianity as a state religion in both halves of the Roman Empire may have been inimical to science at this time. There seemed to be little reason to be concerned about learning how nature worked when most expected the Earthly world to come to an end soon — certainly by 1000, which did not seem that far away during this period.

Medicine was an exception to the general decline. To an extent, it survived the Dark Ages because Christians felt it to be their duty to take care of the sick. During the sixth century, the works of Hippocrates and Galen were studied at monasteries. In addition, the high level of teaching at the school of medicine at Salerno (Italy) during the tenth and

eleventh centuries heralded the revival of science during the later Middle Ages.

Science in China

Chinese society has been known throughout history for the stability of its traditions and its bureaucracy. Yet during the period preceding the 15th century, China was often more successful than Europe in developing and applying scientific knowledge.

Chinese philosophy had gone far in developing theories on matter and living beings. The Chinese seem to have always believed that the blood circulated, for example. Isaac Newton's first law of motion, that a body will not stop moving unless stopped by an opposing force, was stated by Chinese philosophers almost 2000 years before Newton.

Large amounts of empirical data on a number of subjects were accumulated. Most notably, observational astronomy reached a high level as early as the eighth century BCE; it was outstanding for both the quality and quantity of observations. For example, precise Chinese records of the supernova that was visible in 1054 CE allowed present-day astronomers to establish that the supernova was the origin of the Crab nebula.

Around 100 BCE the Chinese discovered that a magnet orients itself toward the South Pole (and also to the North). But Chinese sailors did not use magnets for navigation at sea until the tenth century. The Chinese discovered paper as early as 140 BCE, although they did not use it for writing upon until after 100 CE. The first printed text (in block printing) appeared in China in 868 CE; movable type was invented in China

less than 200 years later. About the same time, Chinese scientists began to make gunpowder. The Venetian traveler Marco Polo reported that the Chinese were using firearms in 1237.

The escapement, the most important part of the mechanical clock, was invented in China in 725 ce. The Chinese were familiar with many other mechanical devices, such as the eccentric and the connecting rod, as well as the piston rod, long before they became known in Europe. Furnace bellows driven by water wheels contributed to the astonishing developments in iron and steel production during the Sung period (960–1279).

The attitude of Chinese society toward nature was quite different from the attitude that developed in Europe during the Renaissance. The Chinese never separated the material from the sacred world, and did not have the conviction that people can dominate nature. They were not interested in developing a scientific method; thus, their theories often remained divorced from observation and experimentation.

Science and mathematics in India

Because of the religious character of Indian civilization, the development of technology was less pronounced in India than in other areas of the world. However, early Indian science excelled in three fields: mathematics, astronomy, and medicine. Their recognition of the true role of zero, which seems so simple today, was among the greatest advances in mathematics.

The Hindu religion endorsed the vast age of the universe very early, and Buddhist philosophy taught that the universe is periodically destroyed and recreated with a similarly long cycle. Indian mathematics was influenced by the idea of these long spans. As a result, Indian mathematicians were interested early on in very large numbers. Mathe-

matics was mainly numerical and was also influenced by the algebraic tradition of the Babylonians. There was little interest in geometry. The Indians used the decimal system, including zero, to express numbers, making it the most successful system for extensive calculations. They were apparently the first civilization in the Old World to realize that zero is actually a number and not just a device to make written expression of numbers unambiguous in a place-value system. Scholars in other societies had recognized the need for a placeholder in numeration, but failed to grasp the pivotal role of zero as a number.

Ancient Indian astronomy was mainly concerned with calendar computation. Calendar computations were required early for religious ceremonies; they were based on the motions of the Moon and Sun. The Indians showed little interest in the motion of the planets. Later, Indian astronomy was influenced by the theories from Babylonia and ancient Greece. The Indian development of spherical trigonometry was an outgrowth of their astronomy. The word *sine* is derived from an Indian word.

Medicine developed very early as well. It was based on preventing disease and on hygiene as much as on curing disease. Hospitals and herbal gardens existed in the third century ce. Health was viewed to be the result of the balance of three elements: air, fire, and water. In relation to the body, these elements became wind, bile, and phlegm, comparable to three of the four “humors” in Western medicine at that time.

Arab science

The Islamic culture, which flourished from about 700 to 1300, played a key role in bridging the gap between the Hellenistic period and the Renaissance. During that period, the Islamic empire became the most advanced civilization

in the Western world. The role of Islamic culture in the development of science is demonstrated by the number of scientific terms with Arabian origins, such as *azimuth* and *algebra*.

There are several factors that contributed to the flourishing of science in the Islamic civilization. Because of intense commercial activity, the Arabs came into contact with a large number of cultures, such as the Indian and Chinese. Several different cultures became part of the Islamic world: the Iranian, Turkish, Jewish, Orthodox and Nestorian Christian, and Gnostic, also known as Sahian or Mandaean. Each of these civilizations had new ideas to contribute to Arab thinking.

A strong unifying factor in the Islamic empire, beside the Islamic religion, was the Arabic language, although various parts of the empire also used Persian, Syriac, or other languages. Many of the works of the ancients have been preserved because they were translated into Arabic. During the sixth century, many important works were also translated into Syriac; when the Arabs conquered Syria, these works were translated into Arabic. Several Hindu works were also translated into Arabic.

A number of centers of learning appeared throughout the Islamic empire. Baghdad developed during the eighth century into one of the most important: Caliph Al-Ma'mun [786–833] founded a “House of Wisdom” in Baghdad that was a center for mathematical research and that also contained an astronomical observatory. Many of the important Greek treatises, such as Galen's medical writings and Ptolemy's on astronomy, were translated at the House of Wisdom. During the tenth century, Islamic Cordova (Spain), which became the richest and largest city in Europe, contained a library of 400,000 volumes.

The Arabs not only translated and

preserved the scientific works of Antiquity and of the Indians, they also contributed to several scientific fields themselves. In astronomy, they made a large number of accurate observations with instruments superior to those of the Greeks. In addition, they compiled astronomical tables that remained in use until the Renaissance. The Toledo tables, compiled by al-Zarkali (also known as Arzachel) about 1029–87, became the basis of the Alfonsine tables that were published in Spain by order of Alfonso el Sabio (Alfonso X of Castile-León). This compilation of planetary and stellar positions remained in use for the next three centuries.

Arabian mathematics blossomed in part because it was rooted in a combination of the mathematical knowledge of the Greeks with that of the Indians. The introduction of Indian numerals, often called Arabic numerals, with their decimal place-value system, simplified calculations. Arab mathematicians added new ideas of their own, especially in solving equations, trigonometry, and numerical calculation.

Other sciences advanced as well. Chemistry developed into an experimental science among the Arabs; substances unknown in Antiquity, such as borax and sal-ammoniac, were prepared by Arab chemists. In physics, as in astronomy, Arab scholars excelled in the craft of instrument making.

Alhazen's *Treasury of Optics* remained influential until the sixteenth century. Medicine was highly developed, and a complete infrastructure for health care existed. For example, in Baghdad, 1000 government-licensed physicians practiced medicine. There were numerous hospitals and even mental institutions where humane treatment of patients was offered. However, the science of anatomy did not progress because dissection of corpses is not allowed by Islamic law.

The knowledge gathered by the

Arabs found its way to Christian Europe through translations made in the twelfth century from Arabic into Latin.

The revival of science in Europe

During the last centuries of the first millennium, a reversal of the decline of Western science and technology gradually took place. Trade and food production started to increase, starting in the northern part of Europe. Water was more abundant in the north than in the Mediterranean countries, and the soil was more fertile.

Science returned to western Europe to some degree during the twelfth century. Although the Christian Church had played an inhibiting role in the development of science in earlier centuries, it was the church that caused much of ancient learning to be preserved. The members of the clergy and of monastic orders were practically the only people who were literate. The emperor Charlemagne, who learned as an adult to read and tried unsuccessfully to learn to write, decreed in 787 that every monastery must establish a school. These cathedral schools became the forerunners of the first universities. Technology, especially crafts and farming, was actively pursued at monasteries. However, the strongest factor in the revival of science during that time in Europe was the establishment of contact with the Islamic culture.

Islamic civilization was at its height during a cultural low point in western Europe that followed Charlemagne. As cities with a more educated population began to develop in Europe, Christian scholars were eager to absorb the knowledge amassed by the Muslims. Toledo (Spain), which had remained a Christian bishopric throughout the Muslim occupation, was one of the important centers of Islamic learning. The city was conquered by Alfonso VI

of Castile in 1085, and many scholars went there to study with the Arabs. The Christians mostly learned about the Islamic culture, however, through the Crusades.

A large number of Greek works became available to European scholars from 1150 to 1270. Some scholars, such as Adelard of Bath and Gerard of Cremona, translated Arabic works. Gerard of Cremona translated Ptolemy's *Almagest* from Arabic into Latin, some of Aristotle's works that had been translated into Arabic, Euclid's *Elements*, and the works of Galen and Hippocrates. Adelard of Bath translated Al-Khwarizmi's astronomical tables. Robert of Chester translated Al-Khwarizmi's *Algebra*. By 1270 the whole corpus of Aristotle's work, a large part of it translated from the original Greek by William of Moerbeke, became known to medieval scholars.

The Scholastics were Christian philosophers of the 13th century. They set out to absorb the newly gained knowledge of the ancients and to reconcile it with teachings of the church. St. Thomas Aquinas, one of the founders of the Scholastic school, argued that knowledge can be obtained through both religious faith and natural reason. He believed that the teachings of Plato and Aristotle, especially those of Aristotle, were compatible with Christian religion. Some other Scholastics, such as Siger of Brabant and Boethius of Dacia (not the well-known Boethius), disagreed. Throughout the early 13th century, it became more and more apparent that Aristotle and the church were on a collision course. As early as 1210, the Parisian Synod decreed that certain of Aristotle's works could not be taught at the University of Paris. After all, they said, Aristotle's works imply that God did not create the world, that there can be no transubstantiation of the host and wine during

communion, that miracles cannot occur, and that the soul does not survive the body. In 1277 the pope issued a condemnation of 219 propositions, including many from Thomas Aquinas, that were tainted with Aristotle's views.

During the 13th, 14th, and 15th centuries, a number of scholars developed a new style of philosophy that was less open to charges of Aristotelianism and therefore not banned under the condemnation of 1277. Roger Bacon wrote in his *Opus maius* ("great work"), c. 1286, that it is wrong to rely only on the authority of past scholars and that experiment is an important means of gaining knowledge. In the 14th century, William of Ockham and Jean Buridan criticized Aristotle's theory of motion. In the 15th century, Nicholas of Cusa (a cardinal in the church) challenged Aristotle's concept of the fixity of Earth.

The technology revolution of the Middle Ages

According to many historians, the first important technological revolution took place during these years. It was a revolution mainly because of two factors: Several technologies from Antiquity that had been forgotten became used again on a large scale, and a series of new inventions brought medieval technology to a more advanced stage than that of the Romans. Many of the tools and machines developed during these times remained practically unchanged until the Industrial Revolution.

The first center of technology during this period was the Far East, but the vast improvements made in everything from communication (printing) to transportation (the rudder) in China during this period seem not to have had a basis in or relationship to science. Gunpowder, for instance, did not arise as a result of understanding the chemistry of combustion; nor did it lead to studies in how chemicals combine or

what it is about chemical reactions that produces heat and expanding gases.

The revival in Europe took on several forms. Landowners reintroduced the rotation of crops, as practiced by the Romans, increasing food supplies substantially. Roads were paved again and transportation and trade profited from important inventions, such as the steerable carriage and the padded shoulder collar for horses. Previously, horses carried a girth band to pull carriages, and because of its choking effect, horses could only pull small weights. Horse-shoes, previously used by the Romans, came into general use during the tenth century, allowing horses to travel over longer distances.

A key technology taken over from Antiquity was the water wheel. In northern Europe, in contrast to Mediterranean countries, water was abundant and the water supply in rivers was dependable. As a result, the water wheel became the most important source of mechanical power throughout northern Europe for many centuries.

Although Europe was the region where extensive sources of water and wind energy changed life the most, it was not the most advanced society of the time, especially in the beginning of the period. Europeans who encountered Chinese civilization, notably Marco Polo in the 13th century, recognized that they were in the presence of a technology that could accomplish much that went beyond the medieval technology of the region dominated by the Roman Church. Arab scholars and scientists also were more advanced than Europeans in the beginning of this period.

Viking explorers had already settled in Greenland and begun a destructive dialogue with the natives they encountered. Soon after 1000 ce the Viking roving reached the Americas. Later Basque whalers probably also visited the Americas. These contacts, however,

did not result in any significant exchanges or expansions of technology.

The technology that made this linkage possible began with the Viking ships, the first Western ships with centered, rear-mounted rudders, and continued with improvements in sail rigging and ship construction. By about 1450 all the elements were in place to produce the caravels of the Portuguese, quickly imitated in one element or another by most of the Western seafaring nations (and distinctly improved upon by the Dutch).

The technology interchange that resulted from the new worldwide linkage was surprisingly small. The biggest influence during this period was the passage of Chinese technology into the West — but that had come over land before during the great age of exploration. By the time European ships reached China, they were already using improved versions of Chinese techniques.

During this period, the center of technology gradually moved toward the west (some would argue that it has continued to do so since then, moving from Asia to Europe, from Europe to North America, and — in our day — from North America back to Asia again). As the center shifted from China to Persia (Iran) under the Arabs and the Arab world in general, pure science began to arise and become something of an influence on the growth of technology. The Arabs, after all, preserved the knowledge of Antiquity that had been lost after the fall of the Roman Empire in the West.

Exposed to such scientists as Aristotle, the best Arabian and Persian thinkers became scientists and mathematicians themselves. The Arabs followed the tradition of Hippocrates and Galen, contributing to the development of medicine and chemistry. Influenced by Alexandrian science, some Arab scholars used water-driven clocks to drive

toys and temple apparatuses. The Arabs and Persians were very careful astronomers and made many technical improvements in the main astronomical instruments of the day, astrolabes and sundials. Otherwise, the Arabs largely transmitted the technology of the East to the West, not changing it very much.

Major advances

ASTRONOMY Although the Arabs accepted Ptolemy's system of cycles and epicycles, they greatly improved observational techniques and developed trigonometry as a part of their astronomical work. Nevertheless, the Arabic translations of Ptolemy's *Almagest* became the standard text for astronomy throughout the later Middle Ages. Astronomy continued to be based on Plato's principle that all observed motions of heavenly bodies had to be explained in terms of uniform circular motions. Ptolemy's and Aristotle's views became incorporated into church doctrine mainly through the efforts of St. Thomas Aquinas. Aristotle's cosmology required a prime mover that keeps the planets and stars moving. The existence of such a prime mover became for St. Thomas his "first proof" of the existence of God.

BIOLOGY Later medieval biology was strongly influenced by Aristotle's method of investigation: Try to find the function and purpose of organic structures. Botany and zoology became separate disciplines. The main interest in botany was medical, while zoology often played a moral and didactic role, emphasizing fables more than facts. Both sciences incorporated tales and myths of all kinds; famous were the so-called bestiaries, stories describing incredible animals and monsters, usually believed literally by the general population. The most accomplished biologist was Albertus Magnus, who

studied plants all over Germany not just for medical or agricultural reasons, but for scientific purposes as well. He also studied a large number of animals, birds, and insects, and ridiculed the fantastic stories from the bestiaries.

CHEMISTRY Chemistry was dominated by alchemy, taken over from Arab sources. The alchemists searched for a method of making gold, and a large number of manuscripts appeared on that subject. The church vigorously opposed alchemy, but there were practitioners within its ranks. Alchemy led to experimentation; several new chemicals, such as mineral acids, and some practical applications of alchemic techniques appeared. Several types of distillation methods were improved; for example, water cooling of the condensing tube was introduced. The distillation of alcohol appeared during the twelfth century, and *aqua vitae*, 96 percent alcohol or 192 proof, was obtained during the 13th century by redistillation. Toward the end of the 13th century, the first oil-based paints appeared.

COMMUNICATION The next major development in communication after the invention of writing came during this period: printing with movable type. In many ways this invention immensely sped up technological development around the world. Just as the mass production of the written word made a big difference, another set of inventions made writing more personal — quill pens and the first pencils. What was written had to stay, for the rubber eraser would not be invented until after this period.

CONSTRUCTION The empirical technology of engineering and architecture underwent its greatest growth since the time of the Romans. Medieval cathedrals developed over the centuries as builders found new ways to solve the problems of building very large structures from stone. Similar technology

could be applied to other large structures, such as town halls or bridges.

Architecture in Europe flowered again in cities, especially with the building of the large cathedrals in northern Europe. New breeds of professional workers — architects, stone masons, and technicians — traveled from building site to building site, bringing their expertise with them. Because of this wandering existence, masons did not belong to guilds or corporations as did the other trades. Because the cathedrals were the first truly large buildings of the Middle Ages, their builders developed a number of construction technologies, such as pulleys, cranes, and other lifting devices, and methods for transporting heavy loads. The building of cathedrals was accompanied by the development of stone quarries. The need to transport stone from quarries to the cathedrals influenced the development of canals and locks.

Much of the monumental architecture of this time is still available for visiting or even in use today. Europe is dotted not only with the cathedrals from this time but also with a great many castles, nearly all constructed during this period. In Asia such giant temples as Angkor Wat in Cambodia were built. In North America the pueblos of the U.S. Southwest eclipsed the apartment houses of the Roman Empire.

Rigid bridges, as opposed to suspension bridges, made several significant advances in the period as engineers struggled with the problem of lengthening the span without damming too much of the river. The increased use of trusses helped improve bridge stability and also aided the construction of buildings in general.

ENERGY Because society in the Middle Ages was not based on slavery and because of the emergence of trade and artisans, energy technology made strik-

ing progress. Many medieval devices such as water wheels, geared wheels, and windmills, had been known in Antiquity — although windmills were first described about 600 CE, just after the end of Antiquity. However, it was only during the Middle Ages that these devices came into use on a large scale. In 1086 there were some 5000 water mills in England. Water wheels were used to drive trip hammers for crushing bark for tanning as well as for grinding grain. Productivity of iron making and working was increased with the introduction, during the twelfth century, of mills driven by animal power or water wheels. The water wheels or squirrel cages put in motion by running dogs were used to drive bellows, allowing an increase in size and temperature of furnaces.

Similarly, the use of wind to power ships was hardly a new idea, but new riggings and ways to steer ships into the wind made wind power more useful than ever. Furthermore, the idea of the water wheel was combined with the idea of the sail to produce the first European-style windmills. Unlike the earlier windmills of the Near East, these had horizontal axes (more like water mills in that way, although less like them in others) and were much better at catching winds from different directions and turning the energy into useful rotary motion.

Coal increasingly became the fuel of choice, first in China and then in Europe, replacing wood as forests dwindled in the face of increasing population. Coal had been known in Antiquity and then forgotten, so it seemed remarkable to Marco Polo that the Chinese burned black rocks. Coal found lying on the ground or in streams was burned for a long time before anyone thought of mining it.

FOOD & AGRICULTURE Several factors contributed to the revival of agriculture in Europe around the tenth century.

Population density, which had become very low partly as a result of a major epidemic during 742–43, started to increase again — only to drop precipitously during the Black Death. A warmer climate than in earlier centuries also contributed to more successful harvests and to population growth. Agriculture in Europe was improved by the introduction of the iron plowshare, about 1000 CE, and the horse collar, in which the pull is placed on the shoulders of the horse instead of the windpipe. More efficient agriculture and food production resulted in greater wealth: Cities blossomed and commerce became more active.

Virtually all of these technological advances had been known earlier in China, but in most cases it is impossible to determine which inventions diffused from China.

MATERIALS Paper-making technology, introduced from China by the Arabs, reached Europe during the twelfth century, and paper mills were established in several cities. This paved the way for printing in Europe, which began at the very end of this period, around 1440. The spinning wheel also appeared around that time.

The reduction of iron ore to metal during this period used the same methods as the metallurgists had developed in Antiquity, but the size of furnaces increased. Several types of carbon steel and cast iron were produced, although the exact role of carbon content in iron was not understood. Some nations produced better iron than others; this became a factor in several major battles of the period. The 14th century saw major changes. Cast iron, long used in China, became common throughout Europe. Blast furnaces appeared around the 14th and 15th centuries in the Liege area. The demand for iron and other metals increased substantially with the introduction of the cannon during the 14th century.

MATHEMATICS Mathematics in Europe was at a very low level during the early Middle Ages. Most calculations were done on the abacus because, before the advent of Hindu-Arabic numerals, mathematical operations were difficult to perform. Leonard of Pisa, also known as Fibonacci, introduced Hindu-Arabic numerals in Europe, although they had been known previously to some European mathematicians. He also is known for the Fibonacci sequence, a mathematical sequence for which each term is the sum of the two preceding terms: 1, 1, 2, 3, 5, 8, 13,

Nicolas Oresme introduced notions that correspond to the idea of rational (fractional) exponents as well as a concept similar to that of a function. He also introduced a graphical system for studying mathematical curves. While his graphs for uniform motion were not based on a coordinate system in the Cartesian sense, they implied (for the specific examples used) a fundamental law of the calculus: The way a function changes determines the area under a curve describing the function; however, such an interpretation is possible only if one already knows calculus.

MEDICINE & HEALTH Medical practice relied on the Hippocratic method combined with the use of herbs and drugs, although astrological influences also were believed to play a role in the course of an illness. Drugs based on arsenic, sulfur, and mercury were used, especially mercury ointments for the treatment of skin disease. Opium was used as an anesthetic during surgery. The art of ophthalmology, developed by Arab physicians, reached a high level and operations removing cataracts were performed successfully.

The monasteries generally preserved the medical heritage of Greece and Rome, and medicine became the most successful practical art in the Middle Ages. During the eleventh century medicine underwent a revival at Saler-

no (Italy), where it reached a high level because of contact with the Arabs in nearby Sicily. During the twelfth century, Montpellier (France) became a medical center. During the 13th century, medical schools appeared in Bologna and Padua (Italy) and in Paris.

Perhaps the single greatest advance in medical technology of the period started during the 13th century when people found that glass lenses could be used to correct vision defects. Spectacles for correction of the almost inevitable farsightedness of old age were first introduced, followed by glasses that corrected the common ailment of myopia (nearsightedness). Although these instruments seem commonplace today, even as they are being replaced by better contact lenses, spectacles were like a miracle for the time. They still seem miraculous to someone with poor eyesight who tries on appropriate glasses for the first time.

PHYSICS The physical sciences were dominated by the views of the ancients, especially by Aristotle's ideas on motion. It was believed that motion is possible only if something continuously pushes the object being moved. William of Ockham was one of the first to introduce the concept of *impetus* and to reject the idea of a prime mover and thus the validity of St. Thomas of Aquinas's first proof of the existence of God. William of Ockham argued that God put the celestial bodies in motion during the Creation, and that they keep moving because they retain the impetus conferred upon them. Jean Buridan perfected Ockham's theory and Albert of Saxony distinguished between uniform and irregular motion.

Although magnetism was known in Antiquity, one of the earliest descriptions of the behavior of magnets is from Petrus Peregrinus. In his *Epistola de magnete* ("letter on the magnet") of 1269 he describes an experimental method of studying magnetism; for

this, he is viewed by many as the first experimental physicist. Robert Grosseteste and Roger Bacon performed optical experiments; Bacon viewed experimentation as an important means of increasing knowledge.

TOOLS Notable advances first seen during this period included those of firearms, mechanical clocks, and suction pumps. The first cannons were built during this period as well. The mechanical clock also appeared during this period and showed up on towers and in cathedrals.

The suction pump, invented at the end of this period, might seem a minor achievement today, but it led to great advances in science. Although pumps were first more prosaically engaged in the vital task of pumping fluids from wells and tunnels, they soon would suggest the barometer and lead to experiments with vacuums. By the end of the 19th century, the suction pump was fundamental to the discovery of subatomic particles.

Virtually unchanged from methods of Antiquity until the early Middle Ages, the textile industry underwent a series of innovations during the 13th century. The most important was the mechanization of fulling and spinning. Fulling is a process in cloth manufacture in which the weight and bulk of cloth is increased by beating on it. It is tedious work by hand. Fulling mills, in which the hammers were tripped by cams mounted on the shaft of a water wheel, appeared in many places, replacing workers that used to beat the cloth with hammers. Because fulling mills depended on waterpower, they often were built outside of cities and thus contributed to the spread of the textile industry outside of towns. Spinning during the early Middle Ages, performed with the so-called "rock" or distaff, improved considerably with the introduction of the spinning wheel in the 13th century. The spinning wheel

was gradually improved and made more "mechanical" during the next several centuries. Looms similar to the ones used in Antiquity remained throughout the Middle Ages, but also underwent improvements during the late Middle Ages and Renaissance.

TRANSPORTATION The roads built by the Romans remained in use throughout Europe during the Middle Ages, although they degraded continuously because very little was done to maintain them. Transport of goods was made difficult by the many tolls along the roadways, but the income from tolls was generally not used to repair the roads. The road situation improved during the second half of the 15th century when, because of an improving economy, traffic and trade between the different countries increased. In cities some roads were paved as early as the twelfth century, but throughout this period highways between cities were never as good as the old paved Roman roads had been.

During the early Middle Ages, most of the goods were transported on pack animals and on small two-wheeled carts. Carts with four wheels and two axles were used for heavy loads, but they remained impractical until the invention of the mobile front axle sometime in the 14th century.

Transport on rivers and canals, especially of heavy loads, developed early, mainly because of the bad shape of roads. The construction of canals started all over Europe during the twelfth century, and the first European locks to make rivers and canals navigable over longer distances appeared by the 14th century. From the 13th century on, the sea became an important road for traffic; the Hanseatic ports start developing around that time. Soon an intense traffic developed between the Hanseatic ports from the North and the ports of Italy, passing through the Strait of Gibraltar.

Shipbuilding improved throughout these times. There is direct evidence from the beginning of the period that more modern methods had been introduced. The type of ship used by the Vikings, with one mast and a square sail, was a great advance. The rudder, mounted on a vertical axis at the aft of the ship, was introduced in the West on

Viking ships; Chinese ships were already using it. Navigation became much more reliable with the introduction of the compass, first a magnetized needle placed on a straw floating on water.

One form of transportation invented near the beginning of this period was used only in dreams for the next

700 years and beyond. Rockets did not carry loads of any kind until the 1930s and did not carry people for another quarter of a century. During the period, although at least one unsuccessful attempt was made to use rockets for transportation, the main use of rockets was in fireworks and war.

CHRONICLE

530

I Tools

The water-powered flour sifting and shaking machine invented in China is mentioned for the first time; this device works like a locomotive's steam engine in reverse, changing rotary motion into the back-and-forth motion needed for sifting; it is the first known machine capable of doing this. *See also* 1780 ENER.

532

II Construction

Eastern emperor Justinian orders the building of Santa Sophia (also called the Hagia Sophia), designed by Isidore of Miletus (Turkey), the first building with a dome large enough to cover a town square. The dome is actually a pendentive, formed by cutting off the sides of a hemisphere to produce a figure that covers a square and then slicing off the top, producing four upside-down "triangles" with curved sides joined at their upper bases. The pendentive dome itself is 37 m (120 ft) across and 14 m (46 ft) high, but rests

on the top of a building, giving it a total height of 61 m (200 ft). Santa Sophia is the largest religious structure of its time. *See also* 126 CE CONS.

534

Σ Mathematics

Koreans introduce Chinese mathematics into Japan. *See also* 602 AST.

537

■ Construction

The Aqua Virgo aqueduct to Rome is destroyed by the Goths. *See also* 338 CE CONS; 1453 CONS.

I Tools

The Roman general Belisarius [b. c. 505, d. 565] installs water wheels on boats moored on the Tiber River during a siege of Rome by the Ostrogoths; this type of water wheel will become very common in European towns during the Middle Ages. *See also* 400 CE ENER.

550

■ Construction

Chryses of Alexandria builds a flood-control dam on a small

river at Dara (Turkey) on the Persian border of the Eastern Roman Empire. As the dam curves upward into the current, it is the first horizontal arch dam. *See also* 560 BCE CONS; 1300 CONS.

→ Transportation

Liang Emperor Luan's *Book of the Golden Hall Master* describes a wind-driven land vehicle built in China by Kaots'ang Wu-Shu. This wind-driven carriage could, it is claimed, carry 30 people and travel hundreds of kilometers in a single day. Sails were also applied to wheelbarrows, and wheelbarrows with sails became a common symbol of Chinese culture in 18th-century Europe. *See also* 1 CE TRAN.

561

■ Construction

The earliest known pointed arch, called an ogive in cathedral architecture, to which we can assign a date is built at Qasr-ibn-Wardan (Syria), although an older pointed arch on a Roman colonnade of uncertain date at Diarbekr (Turkey) also exists. *See also* 1104 CONS.

568

↗ Energy

Women in Northern Ch'i under siege by neighboring kingdoms in China invent matches so they can start fires for cooking and heating. *See also* 1827 ENER.

↗ Transportation

According to most authorities, the Avars bring the newly invented stirrup from China or Korea to Europe when they invade that continent during the sixth century; however, a Greek writer of late in the fifth century implies that stirrups were already in use by the military. *See also* 477 CE TRAN; 580 TRAN.

580

↗ Transportation

Byzantine emperor Maurice Tiberius is the first to mention stirrups in the West. *See also* 568 TRAN.

589

❖ Materials

The oldest known reference to paper for use as toilet paper is made in China. *See also* 110 CE MATR; 751 MATR.



SANTA SOPHIA This great church, built by the emperor Justinian, was intended to be a model for all Byzantine churches. Its first dome fell in an earthquake in 653, but was replaced. From 1453 through 1935 the building was a mosque, and minarets — the towers on the corners — and other structures were added.

600

Communication

A Maya ceramic vessel from about this time shows what appear to be pages from a complex book, suggesting that Maya books had been developing for several centuries; this is the oldest direct evidence of Maya books, of which only three are known today, all from around the 14th century. *See also* 300 CE COMM.

The Chinese print whole

pages with woodblocks, although the earliest known surviving pages are from the 700s. *See also* 704 COMM.

The goose feather (quill) is used for writing at least by this time, since there is a mention of it in the writings of St. Isidore of Seville. Roman writers had used reed pens. *See also* 1565 MATR.

Construction

The Anasazi begin to make pit houses like those of the Mogollons, but Anasazi pit

houses are improved by paving the floors, using stone to line the pits, and sometimes partitioning the house into several rooms. *See also* 500 CE CONS: 750 cons.

Over 4250 m (14,000 ft) high in the Bolivian Andes, 20 km (12 mi) south of Lake Titicaca, people now known as the Tiahuanacans build the large shrine of Tiahuanaco, featuring a temple platform that is 15 m (50 ft) high and 200 m (656 ft) wide at its base, as well as the large, decorated Gateway of the Sun. The site is

known for the excellence of its stone construction without mortar (famous for being so closely fitted that a knife blade cannot be inserted between the stones) and the size of the stone blocks, some weighing more than 90 metric tons (100 short tons). These blocks were quarried 5 km (3 mi) from the site. Although most of the construction is held together by its own weight, some stones are joined by bronze or copper clamps, apparently to earthquake-proof the structure. *See also* 19 BCE CONS.

↗ Energy

The earliest known windmills are built in Persia (Iran); they use a vertical shaft and horizontal sails, partially protected from the wind, to grind grain. *See also* 100 TOOL; 1105 ENER.

🍴 Food & agriculture

In the Nazca region of what is now Peru, filtration galleries called *puquios* are built for irrigation purposes. Tunnels of the same general purpose and design as the qanats had been built to tap underground aquifers by the Assyrians and many subsequent inhabitants of dry regions, including the Spanish. When Spain colonizes the Nazca region, the conquistadores and their followers reintroduce the qanat to the region.

It is believed that forks are introduced for dining by the royal courts in the Middle East; such early forks had two tines and were a replacement for a second knife, previously used to skewer food while the first knife was used for cutting and lifting food. *See also* 1100 FOOD.

Σ Mathematics

About this time Zu Chong-Zhi and his son Zu Geng-Shi calculate π to be between 3.1415926 and 3.1415927. *See also* 635 MATH.

602

★ Astronomy

Korean priests introduce the calendar and astronomy into Japan. *See also* 534 MATH.

court lasts until 1911. *See also* 60 BCE COMM; 748 COMM.

610

🏗 Construction

Influential Chinese engineer Li Ch'un builds the Great Stone Bridge over the Chiao Shui River in northern China, the first example of a segmental arch bridge. It survives intact today. *See also* 600 BCE CONS.

🍴 Food & agriculture

An Italian monk invents pretzels as a reward to children who learn their prayers. He calls the strips of baked dough, folded to resemble arms crossing the breast, *pretiola* ("little reward").

✈ Transportation

Chinese Emperor Yangdi completes a major section of the Grand Canal, linking the Yangtze and the Huang He (Yellow River); this round of construction starts in 605, although construction of the first segments dates back at least until 70. Some parts may have been based on canals dug as early as 500 BCE. *See also* 70 CE TRAN; 1327 TRAN.

615

↗ Energy

Japanese texts mention "burning water" used in lamps, which is thought to refer to petroleum. *See also* 77 CE ENER; 945 ENER.

618

📠 Communication

China starts publication of a court newspaper, with several dozen copies printed. This form of news reporting at the

622

★ Astronomy

Mohammed flees Mecca for Medina, a flight known as the Hegira. The Islamic calendar begins with this year.

628

★ Astronomy

Hindu astronomer and mathematician Brahmagupta denies the rotation of Earth, although most other Indian astronomers of his time believe Earth rotates. *See also* 510 CE AST.

Σ Mathematics

Brahmagupta writes *Brahmasphuta siddhānta* ("the opening of the universe"). It concerns mensuration, trigonometry, and algebra, including excellent work on Diophantine equations and the first rules for operating with zero and with negative numbers as well as a method for approximating square roots. *See also* 665 MATH.

630

📠 Communication

Etymologiae sive origine ("etymologies") by Isidore of Seville [b. Cartagena (Spain), c. 560, d. Seville (Spain), April 4, 636] is a first attempt at a general synthesis of pre-Christian learning. Drawing heavily on Pliny the Elder, it is filled with legends and immensely popular at the time (about 1000 manuscripts survive). *See also* 77 CE COMM.

635

★ Astronomy

A clear statement of the rule that the tail of a comet always points away from the Sun is written in China. *See also* 1540 AST.

Σ Mathematics

The value of π is given as 3.1415927 (using decimals) in the official history of the short-lived Sui dynasty of China. *See also* 600 MATH.

640

✈ Transportation

For the last time, the canal begun by Pharaoh Necho about 1200 years earlier is restored to use, this time by the Arab general 'Amr ibn-al-'As. It is covered in sand for good sometime in the eighth century as later Arab rulers allow the entire canal system of Egypt to fill in, resulting in massive famine when there is no longer irrigation for Egypt's fields. *See also* 100 TRAN; 1856 TRAN.

Brahmagupta

[b. central India, c. 598, d. c. 665]

This Indian mathematician applied his mathematical skills to solving astronomical and geometrical problems with mixed success — he made as many errors as correct applications. However, his arithmetic, which included negative numbers and zero, was much better (although still containing a few errors) and his algebra, especially his work with Diophantine equations, generally excellent.

641

Σ Mathematics

The Museum in Alexandria, home to such mathematicians as Euclid, Archimedes, Eratosthenes, Apollonius, and Pappus, ceases to exist. *See also* 300 BCE MATH.

643

♥ Medicine & health

The Chinese physician Chen Ch'üan, who dies in this year, is the first person to have noted the symptoms of diabetes mellitus, including thirst and sweet urine. *See also* 1889 MED.

646

COMMUNICATION

The final destruction of the Library at Alexandria probably takes place this year. A famous story, perhaps true, says that when the Muslim general 'Amr ibn-al-'As captures the city he asks the Caliph what to do with the Library. He is informed that if the books agree with the Koran they are superfluous, but if they disagree they are blasphemous and should be destroyed, which is what the general does. *See also* 391 COMM.

650

♥ Medicine & health

Greek physician Paul of Aegina [b. c. 629, d. c. 690] lists the symptoms of lead poisoning. *See also* 400 BCE ECOL; 1767 MED.

662

Σ Mathematics

Bishop Severus Sebokht of Syria mentions Hindu numerals as using only nine digits. *See also* 683 MATH.

665

Σ Mathematics

Brahmagupta writes *Khandakhadyaka*, primarily a work concerning astronomy. It also contains a method for interpolation that is used to compute the values of the sine function. *See also* 628 MATH.

673

❖ Materials

Callinicus [b. Heliopolis, Egypt, c. 620] invents a substance that will burn in water and thus be a weapon against wooden ships; it is known as sea fire, wet fire, or Greek fire. Other substances had been previously used to ignite wooden ships in sea battle, such as a form of burning pitch introduced as a naval weapon by Rhodes in 190 BCE, but sea fire, whose exact composition remains unknown, was a specific wettable compound used primarily by the Byzantine Greeks during sieges of Constantinople. One school of thought holds that it may have contained quicklime, which produces heat when in contact with water.

675

★ Astronomy

The first sundial in England is built in Newcastle. *See also* 25 BCE ENER.

Telling time

In ancient time-measurement systems, including those of both Egypt and China, daylight and nighttime were each given 12 hours. This was convenient for use with sundials, which are known from Egypt as early as 1500 BCE, although telling time "by the Sun" probably predates the first humans. Because the length of daylight and nighttime varies with the season, so did the length of the Egyptian hour. When water clocks came into use, shortly after sundials, a conflict between the two forms of measurement was apparent.

A water clock works because water from a container flows through an opening at a nearly steady rate. The amount of water in another container is used to move an indicator of some kind — in simplest form, the level of water in a container. Since the water flows at an almost steady rate, the indicator shows the hours as it moves along a marked face. But when the length of the hour changed from season to season, a different water clock was needed for each month. Ancient peoples solved this problem in various ways, such as by having different marked faces for each month. In that way the water clock was never far out of line with the sundial, which also remained in use. Later, instead of modifying water clocks to change with the seasons, sundials were constructed to show hours of the same length all year.

In the eighth century CE, the Chinese began to fashion water clocks with primitive escapements. The escapement is a ratchet that causes a wheel to move only so far and then stop, so that there is no runaway action when the clock is fully loaded with water. Continuous motion is replaced with discrete "ticks." By the beginning of the 14th century, the concept of an escapement was known in Europe. The escapement was used to slow down the motion of a falling weight attached to it by a cord or chain. This motion could then be converted with gears to turn the dial of a clock. Mechanical clocks using escapements and weights were gradually improved and put in towers all over Europe.

683

Σ Mathematics

The first uses of a "goose-egg" sign for zero appear about this time in Cambodia and Sumatra, although the Chinese had long used an empty space as a placeholder and later Mesopotamian numeration also used a sign as a placeholder; it is not clear when

zero comes to be understood as a number and not just a placeholder. *See also* 662 MATH; 876 MATH.

687

► Construction

Caliph Abd al-Malik [b. Medina, 646, d. 705] orders the Dome of the Rock built in Jerusalem over the rock where

Muslims believe Mohammed ascended to heaven and Abraham offered his son as a sacrifice to God. *See also* 532 CONS; 691 CONS.

688

■ Construction

The empress Wu Tse of China has a pagoda 90 m (294 ft) tall built of cast iron. *See also* 695 CONS.

691

■ Construction

The Dome of the Rock, a large wood-and-brass dome covered with gold over an octagonal base, is completed in Jerusalem. One of the largest structures of this period, with a basal circumference of 161 m (528 ft) and a height of 34 m (112 ft), it survives in essentially unchanged form. *See also* 687 CONS; 1419 CONS.

695

■ Construction

The empress Wu Tse has a cast-iron column made from about 1325 tons of iron to commemorate the ancient Chou (a.k.a. Zhou) dynasty of China, which ended nearly a thousand years earlier. *See also* 688 CONS; 954 MATR.

700

■ Construction

In Cholula, just east of the Valley of Mexico, the largest pyramid ever is built, larger than either the Pyramid of the Sun in nearby Teotihuacán or, in terms of volume, the Great Pyramid of Khufu (Cheops)

in Egypt. *See also* 100 CE CONS; 750 ARCH.

Σ Mathematics

About this time the first printed reference to “ball arithmetic,” which may have been an early form of the abacus, appears in Chinese texts. The text implies that the abacus goes back to the second century CE. *See also* 500 CE MATH; 967 MATH.

704

↳ Communication

Between 704 and 751 the earliest printed text known to survive, a Buddhist charm scroll, is created. Woodblocks are used to print the images. *See also* 600 COMM; 868 COMM.

707

♥ Medicine & health

Caliph al-Walid bin Abdul Malik founds the first Arabic hospital, or bimaristan, in Damascus (Syria). It specializes in treating patients with chronic illnesses, notably leprosy. *See also* 1154 MED.

724

I Tools

Buddhist monk I-Xing and Chinese engineer Lyang Lingdzan build a water clock that has an escapement, the device that causes a clock to tick. The escapement opens and closes a valve, making the flow of water maintain a more constant rate. The clockwork is used to power various astronomical devices rather than to indicate the hour. *See also* 500 TOOL; 1088 TOOL.

725

★ Astronomy

English scholar the Venerable Bede [b. Jarrow, Durham, England, 673 or 672, d. Jarrow, c. 735] writes various works about this time. His famous *Ecclesiastical History of the English People* dates from 731, but his first version of a history of the world was probably composed about 704.

Although most noted as a historian, Bede also writes about the calendar, the shape of Earth, and the tides, giving a correct account in each case.

748

↳ Communication

The first printed newspaper available to the public appears in Beijing, China. *See also* 618 COMM.

750

▲ Archaeology

The city of Teotihuacán falls to unknown invaders about this time, after 150 years of decline. *See also* 100 CE CONS.

▷ Chemistry

Arabic alchemist Geber describes how to prepare aluminum chloride, white lead,

nitric acid, and acetic acid. *See also* 300 CE CHEM; 900 CHEM.

↳ Communication

The Hohokam people living in what is now New Mexico discover etching; by covering part of a shell with pitch and exposing the rest to acidic cactus juice, they etch decorations into the shells. Etching will be rediscovered in Europe in the 15th century.

■ Construction

The Anasazi leave their pit houses at least in summer and move into masonry buildings that consist of long lines of rooms that face the old pit houses. Different rooms in the masonry houses are used for different purposes, such as sleeping, cooking, or storage. The pit houses may be retained for ceremonial use simply because they are warmer than the row houses in winter. *See also* 600 CONS; 800 CONS.

❖ Materials

In Egypt, the practice of using a thin film of a metal oxide, called a luster glaze, is developed for use on glass, although glazes will become common only when adapted for use on pottery. *See also* 850 MATR.

Geber (Abu Musa Jabir ibn Hayyan)

[b. Al-Kufah (Iraq), c. 721, d. Al-Kufah, c. 815]

Geber was probably a Sufi (a believer in a mystical branch of Islam) who was close to the court of Caliph Harun al-Rashid. He may have been responsible for the concept of an “elixir” that could be used to change base metals into gold — he believed that a proper combination of sulfur and mercury produced gold. His works are important because of the care with which he described his chemical preparations, which included dyes as well as acids, salts, and various forms of metals. His followers often attributed their own work to him, leading to considerable confusion about which books are actually his.

Alchemy from start to finish

Alchemy was not merely misguided chemistry; it made many contributions to chemistry. Alchemy was, however, a magical or mystical way of looking at the world. Alchemy seems to have started with the Taoists in China and the Pythagoreans in Greece sometime after the sixth century BCE. As the ideas of alchemy developed and moved westward, Taoist ideas about chemicals were combined with Pythagorean number mysticism. Another alchemical tradition came from the Egyptian embalmers, such as Zosimus, who wrote one of the first summaries of alchemical ideas extant.

In China, the early alchemists were searching for what came to be called the elixir of life, a way to provide immortality. Some of their accomplishments were remarkable, such as the embalming of the Lady of Tal. This woman was buried about 186 BCE in a double coffin filled with a brown liquid containing mercuric sulfide and pressurized methane. Under these conditions there was no observable deterioration of her flesh when she was exhumed after more than 2000 years. She appeared more like someone who had died only a week or so before.

Chinese alchemy passed on to the Indians, who were more interested in using alchemical ideas to cure diseases. Eventually, the Arabs put together the ideas from the East with the Alexandrian tradition of alchemy that had descended from the Pythagoreans. In this form of alchemy, astrological influences were important. Chemical reactions were thought to occur because of the influences of the planets. Numerology and even the shapes of the vessels also helped determine reactions. In this tradition, the elixir of life became mingled with the concept of a

philosopher's stone, an object whose presence would enable one to transmute other metals into gold. To some degree, the mingling of the elixir with the philosopher's stone was due to Geber, who was the first to use the term "elixir." Geber's writings from the eighth century CE so dominated alchemy that a talented chemist of about 400 years later is known as "the False Geber" since, like many other alchemists, he signed all his works with the name of the master.

Despite mystical theories of matter, the alchemists managed to develop various practical tools, including the first strong acids and the distillation of alcohol.

During the Renaissance, the West absorbed Arabic alchemy along with more conventional science. By the 16th century, alchemy was being practiced mainly in Europe. Paracelsus was one of the alchemists who was also a successful physician and scientist. Some of his achievements include the first known description of zinc, the recognition that coal mining causes lung disease, and the use of opium to deaden pain. Paracelsus proclaimed that he had found the philosopher's stone and would live forever. Unfortunately, he drank a lot and died before he was 50 in a fall that some attribute to drunkenness.

Libavius was a follower of Paracelsus who also was a successful scientist despite his belief in alchemy. His 1597 book *Alchemia* is the first good book on chemistry. The tradition of alchemy persisted well into the 18th century. Newton spent much of his later life trying to find the philosopher's stone, and may have gone mad from mercury poisoning caused during his experiments. Finally, Lavoisier, in the later part of the 18th century, put together a scientific view of chemistry that effectively wiped out the alchemical tradition that had persisted for 2000 years.

751

Materials

The Arabs learn paper manufacture from the Chinese at Samarkand in central Asia (Uzbekistan). *See also* 589 MATR; 793 MATR.

752

Biology

The earliest known reference to a plant virus is made in a poem included in the *Man'yoshu* ("collection of ten thousand leaves"). The poem, written by the Japanese empress Koken in this year, mentions the unusual sum-

mer appearance of leaves on a plant called eupatorium, which is caused by the eupatorium yellow-vein geminivirus. The yellow leaf veins give the plant an autumnal appearance that catches the empress's eye.

Materials

After gold is discovered in Japan in 749, work is completed this year on casting and gilding a 16-m- (53-ft-) tall statue of Buddha in Nara, Japan. Cast in bronze in 40 sections, the statue contains more than 450,000 kg (1,000,000 lb) of the alloy of copper, tin, and lead along with several hundred kg of

pure gold. *See also* 494 CE ARCH; 793 CONS.

775

Mathematics

Various Hindu works on mathematics are translated into Arabic. *See also* 628 MATH.

782

Communication

Charlemagne calls on scholar Alcuin of York [b. England, c. 732, d. Tours, France, May 19, 804] to organize education in his kingdom of the Franks and Lombards; Alcuin estab-

lishes schools associated with important cathedrals and also teaches Charlemagne to read. *See also* 796 CONS.

789

Mathematics

Charlemagne introduces the royal foot as the unit of length, and the "Karlsfund" (about 365 grams) as a unit of weight. *See also* 2100 BCE MATH; 1101 MATH.

793

Construction

The Japanese emperor Kammu [b. 737, d. 806] orders

793–796

the capital at Nara to be abandoned because it is dominated by Buddhist monasteries. The new capital, now known as Kyoto, built 24 km (15 mi) away, is a masterpiece of urban planning, designed for a population of 100,000. It is modeled somewhat after the Chinese city of Chagan and surrounded by a moat; boulevards are numbered and separate the city into 1200 identically sized blocks. *See also* 752 MATR.

❖ Materials

The art of paper manufacture spreads from Samarkand to Baghdad. *See also* 751 MATR; 900 MATR.

796

■ Construction

The only building of any importance erected in western Europe between the fall of Rome and 1000 CE is theminster in Aix-la-Chapelle, constructed as a tomb for Charlemagne, started this year and completed by Pope Leo III in 805; it is destroyed in the following century by Norman raiders and re-erected in 983 by Emperor Otto III. *See also* 1000 CONS.

800

★ Astronomy

Machu Picchu, built in Peru by the Inca civilization, contains an “astronomical altar,” used to location exact positions of the Sun and Moon. *See also* 1450 BCE CONS; 829 AST.

⌚ Communication

The phonetic script called kana is developed for writing Japanese. The simplified script

is much easier to learn than Chinese ideograms, and women as well as men become literate — resulting in the women of the next couple of centuries writing some of the great works in the Japanese language, notably *Tale of Genji* by Lady Murasaki.

■ Construction

The Anasazi begin to construct the first of the multistory apartment dwellings for which they are famous; built with masonry walls more than 1 m (3 ft) thick, the pueblos, as the Spanish later name them, contain dozens of families. *See also* 750 CONS.

■ Food & agriculture

Using water from the Gila and Salt rivers, the Hohokam of what is now Arizona construct by this time one of the most extensive irrigation networks of dams and canals in the Americas. *See also* 550 CONS; 1209 TRAN.

The rigid horse collar in which the main load is on the chest and skeletal system of the horse is introduced in Europe, roughly a thousand years after its first use in China. The evidence for this is that horse collars are shown on the Bayeux Tapestry showing scenes in France and England in 1066 (probably woven before 1092). *See also* 110 BCE TRAN.

❖ Materials

During the Tang dynasty in China, stoneware pottery is made, and perhaps an early form of porcelain, a hard translucent white ceramic from fine clay, is invented. *See also* 200 CE MATR; 1100 MATR.

A predecessor of the blast furnace is used for making cast

iron in Scandinavia. *See also* 695 CONS; 1200 MATR.

The ancestor of paper money is in use in China, essentially as bank drafts on money deposited that can be exchanged for hard cash at a later date or at a different bank. *See also* 600 COMM; 812 MATR.

Σ Mathematics

The decimal system is introduced by the Arabs into Spain. *See also* 1030 MATH.

A complete translation of Euclid’s *Elements* is made into Arabic. *See also* 300 BCE MATH; 1142 MATH.

Chinese mathematicians use the method of finite differences to solve equations. This is an iterative process that provides approximate solutions that can be as close as is needed to the actual solution. *See also* 628 MATH; 1209 MATH.

807

★ Astronomy

Life of Charlemagne by Einhard [b. Seligenstadt (Germany), c. 770, d. Mulheim, c. 830] provides the first Western reference to sunspots. *See also* 840 AST.

812

❖ Materials

The Chinese government takes over the issuing of paper bank drafts, the ancestor of paper money. *See also* 800 MATR.

815

⌚ Communication

Bayt al-Hikma, a science library in Baghdad, is founded. *See also* 646 COMM.

827

★ Astronomy

The first translation of Ptolemy’s *Almagest* into Arabic is made about this time. *See also* 140 CE AST; 850 AST.

829

★ Astronomy

Arab and Persian astronomers build observatories that use very large instruments to measure positions of stars more accurately. *See also* 300 BCE AST; 1424 AST.

830

I Tools

The *Utrecht Psalter* provides the oldest pictorial evidence of a crank handle for turning wheels in the West, nearly a thousand years after the Chinese use of such handles; the illustration shows a man sharpening a sword on a grindstone. There is some archaeological and written evidence that the Romans knew of the crank, but crank handles were not in regular use in Roman times except for hand mills. *See also* 300 CE TOOL.

832

⌚ Communication

Caliph Al Ma’mun [b. Baghdad, 786, d. Tarsus, Cilicia, August 833] founds The “House of Wisdom” in Baghdad, a center for study and research similar to the earlier Museum in Alexandria. Its most famous scholars are the mathematicians Muhammad ibn Musa Al-Khwarizmi [b. Khwarizm (Uzbekistan), c. 780, d. c. 850] and the Banu

Musa ("sons of Moses"), three brothers who direct the translation of Greek works from Antiquity. *See also* 815 COMM; 850 TOOL.

Earth science

In his world geography, based largely on Ptolemy, Al-Khwarizmi overestimates the size of Earth, giving it a circumference of 64,000 km (40,000 mi). *See also* 140 CE EAR.

Mathematics

Al-Khwarizmi about this time writes *De numero indorum* ("concerning the Hindu art of reckoning"), which gives a set of rules for computing with Hindu-Arabic numerals. This work, when translated, introduces Hindu-Arabic notation to Europe. *See also* 775 MATH; 835 MATH.

Tools

Muhammad Al-Khwarizmi about this time describes the astrolabe, which he probably learns of from Hellenic sources. It is used to find rising and setting times for a celestial body, the altitude of the body above the horizon, and the body's azimuth (position along the horizon as measured from true north). *See also* 400 CE TOOL; 1210 TOOL.



835

Mathematics

Al-Khwarizmi's *Al-jabr wa'l muqābalah* ("restoring and simplifying"), known in the West as *Algebra*, gives methods for solving all equations of the first and second degree with positive roots. From this work comes the origin of the word *algebra*. Al-Khwarizmi's own name is the source of the words *algorism* and *algorithm*. *See also* 628 MATH; 1075 MATH.

840

Astronomy

Abū al-Fadl Ja'far ibn al-Muqtāfi is the first Arab known to record sunspots. *See also* 807 AST; 1611 AST.

850

Astronomy

Egyptian astronomer and geographer Afragamus (Abu-al-'Abbas al-Farghani) [b. c. 820, d. 861] presents Ptolemy clearly in Arabic. *See also* 827 AST; 900 AST.

Materials

In China, *Classified Essentials of the Mysterious Tao of the True Origin of Things*, attrib-

ASTROLABE There are many different versions of the astrolabe, a tool used before the more modern sextant to locate the specific positions of heavenly bodies. Small ones were made to be carried by navigators while very large astrolabes that could not be moved from place to place were one of the main tools of early astronomers.

uted to Zheng Yin, describes a primitive form of gunpowder. The book warns against mixing the powder because of the danger of burning both the experimenter and the house in which the experiment is taking place. *See also* 1044 MATR.

The Egyptian practice of using a thin film of a metal oxide, called a luster glaze, on glass is adapted by Umayyad potters for use on ceramics. *See also* 750 MATR; 1100 MATR.

Tools

The Persian brothers known as Banu Musa write a book on automatons, *Kitab al-Hiyal* ("the book of ingenious devices"), partially based on the work of Heron of Alexandria. About a hundred devices and how to use them are described. *See also* 832 COMM; 1180 TOOL.

Transportation

The modern saddle harness is in use in Europe. *See also* 580 TRAN.

860

Mathematics

The Arabic philosopher Al Kindi [b. Kufah, Iraq, c. 801, d. Baghdad, 873] working at the House of Wisdom in Baghdad writes several works on arithmetic, infinity, geometry, optics, and Aristotle.

Transportation

Vikings discover Iceland. *See also* 982 EAR.

868

Communication

The *Diamond Sutra* is printed in China on May 11 according

to the notice from Wang Jye, its printer. This is the earliest complete printed book (actually a scroll) extant, found in 1900 by Aurel Stein in a cave in Kansu (a.k.a. Gansu) province, China. The *Diamond Sutra* consists of seven large sheets, one with a woodcut picture, pasted together to make the scroll. *See also* 704 COMM; 1440 COMM.

876

Mathematics

The symbol for zero is used in an inscription in India, the first known appearance of this symbol in India, although both the concept and the symbol originated separately earlier. *See also* 683 MATH; 967 MATH.

880

Mathematics

Arabian mathematician Thabit ibn Qurra (a.k.a. Thebit) [b. Harran (Turkey), 836, d. Baghdad (Iraq), February 18, 901] translates Greek mathematical works, generalizes the Pythagorean theorem for all triangles, and tries to solve the problem of establishing Euclid's fifth, or parallel, postulate on the basis of the previous four postulates. *See also* 450 CE MATH; 1824 MATH.

Thabit proposes a formula that generates pairs of amicable numbers — numbers for which the sum of divisors of one number are equal to the sum of the divisors of the other number and vice versa. The smallest such pair consists of 220 (divisors 1 + 2 + 4 + 5 + 10 + 11 + 20 + 22 + 44 + 55 + 110 = 284) and 284 (divisors 1 + 2 + 4 + 71 + 142 = 220). Thabit also discusses

magic squares. *See also* 300 BCE MATH; 1020 MATH.

❖ Physics

Thabit develops a theory of static equilibrium covering beams, levers, and other bodies. *See also* 250 BCE TOOL.

900

★ Astronomy

Arabian astronomer Albategnius (Abu-'Abdullah Muhammad ibn Jābir Al-Battānī) [b. Harran (Turkey), 858, d. Samarra (Iraq), 929] refines Ptolemy's work by making more careful measurements and introduces the use of trigonometry to Arabic astronomy. He calculates the length of the year and determines more accurately than his predecessors the precession of the equinoxes. *See also* 850 AST.

Al-Razi, or Rhazes (Abu-Bakr Muhammad ibn Zakariyya Al-Razi)

[b. Rhages (Iran), c. 845, d. Rhages, 930]

Al-Razi was one of the most important physicians of medieval times. He compiled a vast multivolume encyclopedia that included all medical knowledge of the time, including work handed down from Galen and other ancient Greeks. He was aware of the psychological aspects of health and of the relationship between nutrition and health. He was the first to use opium as an anesthetic, plaster of Paris for casts, and animal guts for sutures.

❖ Chemistry

The Persian physician and alchemist al-Razi, best known by his Latinized name of Rhazes, is the first to classify chemical substances into min-

eral, vegetable, animal, and derivative. He further classifies minerals into metals, spirits, salts, and stones and describes how to make plaster of Paris and metallic antimony. *See also* 750 CHEM; 1250 CHEM.

■ Construction

The Mississippian city now called Cahokia, near the confluence of the Mississippi and Ohio rivers, features a shrine atop a 6 hectare (15 acre), 30-m- (100-ft-) high temple mound and a local population of about 10,000. The temple mound is at this time the third largest structure of any kind in the Americas (after two pyramids in what is now Mexico). *See also* 700 CONS.

■ Food & agriculture

Arab chemists and physicians prepare alcohol by distilling wine. *See also* 3500 BCE FOOD; 1110 FOOD.

❖ Materials

The art of paper manufacture spreads from Baghdad to Cairo. *See also* 793 MATR; 1100 MATR.

Around this time real paper money — that is, printed paper used as a medium of exchange — is in use in Szechwan Province in China. *See also* 800 MATR; 1107 MATR.

Σ Mathematics

The astronomy books of Albategnius offer the main means for European scholars to learn of trigonometry. The version in Albategnius's work is built mainly on use of the sine function. *See also* 628 MATH; 980 MATH.

♥ Medicine & health

Al-Razi (Rhazes) writes the

first scientific paper on infectious diseases, describing smallpox and measles. His multivolume *al-Hawi* ("comprehensive book") includes all medical knowledge of the time and is used in training physicians until the 1600s. *See also* 400 BCE MED; 1000 MED.

A school of medicine is founded in Salerno (Italy). It flourishes for centuries, becoming the University of Salerno in the twelfth century. *See also* 1150 MED.

910

↳ Communication

Persian scholar Al-Farabi (a.k.a. Alfarabicus) [b. Wasij, near Farābī (Turkistan), 870, d. Damascus, Syria, 950] flourishes, writing perhaps 117 books on logic, metaphysics, medicine, music, and fundamental principles in science. Because he reconciles the works of Aristotle to Islam, he is accorded the title "the Second Teacher" — Aristotle being the first. *See also* 350 BCE AST; 1156 EAR.

940

★ Astronomy

The Dunhuang star map is produced in China; it uses a Mercator projection, the first known use of this map projection. *See also* 1568 COMM.

945

➤ Energy

The Chinese emperor Tian Kiao urges the Chinese to use petroleum for heating instead of wood to counter deforestation. *See also* 615 ENER; 1859 ENER.

954

❖ Materials

Emperor Shih Tsung has the largest single piece of cast iron in ancient China made to celebrate his campaign against the Tartars. Known as the Great Lion of Tsang-chou, it weighs about 40 tons. *See also* 695 CONS; 1105 CONS.

967

Σ Mathematics

Gerbert of Aurillac [b. Aurillac, Auvergne (France), c. 945, d. Rome, May 12, 1003], later Pope Sylvester II, introduces the abacus and Hindu-Arabic numerals to Europe (although the new method for writing numbers does not catch on at this time). He seems to have been unaware of zero. *See also* 876 MATH; 1000 MATH.

976

☒ Tools

Chang Ssu-Hsün invents the chain drive for use in a mechanical clock. *See also* 724 TOOL; 1000 TOOL.

977

♥ Medicine & health

A hospital in Baghdad is founded employing 24 physicians. It contains a surgery and a department for eye disorders.

980

Σ Mathematics

Abū'l Wafā' al Buzjānī (a.k.a. Abū'l-Wefā) [b. Buzjān (Iran), June 10, 940, d. Baghdad (Iraq), July 15, 998] intro-

duces the tangent ratio to Arabic mathematics and further develops spherical trigonometry, basing his work more on Indian trigonometry than on Greek. He translates Diophantus into Greek. *See also* 900 MATH; 1220 MATH.

982

Earth science

Vikings led by Eric the Red set up their first camp on Greenland, establishing a larger colony three years later. *See also* 860 TRAN.

983

Transportation

In China, Qiao Wei-Yao, concerned about the amount of stealing taking place as boats are hauled over spillways, invents the lock for canals. Previously, boats frequently

broke up as they were being hauled; people waiting for just such a moment would dash into the wreckage and steal as much cargo as possible. *See also* 610 TRAN; 1253 TRAN.

Early surgery

Surgery is perhaps the oldest form of medicine. The practice of making holes in the skull, or trephining, is prehistoric, while one of the most important early Egyptian papyruses, the Edwin Smith Papyrus of about 1700 BCE, is a list of surgical techniques.

When young Galen learned his surgery in Pergamum around 150 CE, he acquired many of the skills that had been taught since the time of Hippocrates. These are still employed by surgeons today. He learned to set fractures and replace dislocations, to stitch or strap torn muscles or skin (tying off blood vessels along the way), and to cut or tie off hernias. The common invasive techniques included removal of growths of all kinds and of stones from the easily accessible bladder, trephining to relieve pressure (still used), and drainage of fluid that had collected in various body cavities.

After Galen moved to Rome in 162, he dissected many animals and developed a clever (but mistaken in important details) theory of how the body functions — advancing knowledge much more than practice. In the 150 years after Galen's death, his reputation quietly grew; by the fourth century, he was the recognized authority for all medicine in the West and soon in the Arab world as well. While Galen's view of medicine prevailed, the slow, anonymous growth of surgical practice continued. By the seventh century, for example, surgeons had learned to perform tracheotomies when needed and to handle aneurysms if they were located in accessible places.

Arab doctors advanced medical standards of treatment, including roles for immunization, anesthesia (hashish), diet, and cleanliness, but they failed to go beyond a limited understanding of Galen in surgery, largely because Islamic practice was against deliberate bloodshed (except in war or as punishment). The Arabs separated surgery from medical practice, a division that passed over to the West. Surgeons were the lower class of practitioners, while physicians, whose closest approach to surgery was

to let blood, were the elite. For a time the barbers who cut hair and beards were also the surgeons who cut skin and organs. These barber-surgeons of the West were hampered by a lack of anesthetic beyond strong drink (although some knew of opium-based concoctions that were better) and a belief that pus was good for healing. Speed was essential because of the patient's pain, and the most successful procedures were the most external, such as lancing boils or removing cataracts. Amputation of limbs was frequently needed because of the lack of cleanliness in treating minor wounds, leading surgeons to develop considerable skill at the process. Cauterization — sealing off blood vessels by searing flesh — was found to be easier and thus was more commonly practiced than use of ligatures to tie off arteries and veins.

In the East, the surgical traditions were not much different from those in the West. In India, surgeons performed much the same kind of operations that Galen learned and at about the same time. In China, despite advanced ideas on circulation of the blood and use of biological substances (some from animals as well as the better recognized herbal medicines), acupuncture was more emphasized than invasive surgery.

About 1275 surgery in the West began a slow improvement. The scalpel, which had been replaced by ordinary knives, was revived. In 1543 the great work of Vesalius corrected many misunderstandings about human anatomy, with excellent and accurate illustrations. Still, it was not until the 18th century that the barber-surgeons in France and England were completely replaced by medical surgeons. Shortly before that time Ambrose Paré introduced boiling oil to control infection in wounds, which surprisingly was a great improvement over previous practices. The widespread use of firearms probably contributed to increased knowledge on how to remove segments of gangrenous intestine.

Despite cycles of refinement of technique, there was little overall improvement in surgical practice from Antiquity until the introduction of good anesthetics in the mid-19th century. When surgeons could work deliberately on completely anesthetized patients, modern practice truly began.

984

❖ Physics

Mathematician Abu Said al-Ala Ibn Sahl describes the sine law of refraction, known as Snell's law, in *On the Burning Instruments*. He also advances the concepts of mirrors based on conic sections. *See also* 900 MATH; 1621 PHY.

**Avicenna (Abu-Ali Al-Husein ibn Abdullah ibn Sina)**

[b. Bukhara (Uzbekistan), 980, d. Hamadan (Iran), June 1037]

Avicenna is considered the greatest Arab physician today and was recognized as such during his lifetime as well. Rulers of various warring states of the disintegrating Arab hegemony considered Avicenna one of the spoils of war. In addition to his many writings concerning health and medicine, Avicenna argued that alchemists would never be able to transmute base metals into gold. He also transmitted many of Aristotle's views to the wide audience he obtained for the hundreds of books attributed to him.

985

☒ Tools

Gerbert of Aurillac invents a type of escapement consisting of an oscillating horizontal arm that controls the speed of a gear. *See also* 724 TOOL.

986

☒ Earth science

Bjarni Herjolfsson, sailing from Iceland to Greenland, gets lost and sights the Americas, but does not land; eventually he finds Greenland. *See also* 982 EAR; 1001 EAR.

987

★ Astronomy

At Chichen Itza in Yucatán, Mexico, an observatory is built to measure the risings and settings of Venus and the Sun. *See also* 800 AST; 1259 AST.

999

Σ Mathematics

French mathematician Gerbert of Aurillac becomes Pope Sylvester II. *See also* 1000 MATH.

1000

★ Astronomy

A calendar with a year of 360 days divided in 12 months of 27 or 28 days is introduced in India. Since this falls short of an actual year, the Indians add an extra month at regular intervals. It is also possible that Indians use 12 months of 30 days each, a plan that still falls short of the actual length of the year. *See also* 900 AST; 1582 AST.

About this time the seven-day week is introduced to China by Persians or by merchants from central Asia; before this the most common Chinese week ran ten days.

Chinese sages, who had recognized the Moon's role in controlling tides for about a thousand years, report that the Sun also has a role in controlling tides. *See also* 300 BCE EAR; 1687 EAR.

■ Construction

About this time the church of Hosios Loukas is built at Phocis, near the Gulf of Corinth; made of stone, brick, and tile in the shape of a cross within a square, it typifies the fortresslike nature of the churches of Byzantium. *See also* 532 CONS; 1065 CONS.

☒ Earth science

The Vikings, led by Leif Ericson (son of Eric the Red) reach America about this time. *See also* 986 EAR; 1492 EAR.

☒ Food & agriculture

The Arabs introduce the lemon plant to Sicily and Spain.

◊ Materials

The people along the coast of Ecuador learn to smelt platinum, although how they obtain the high temperatures required remains a mystery (along with the exact date that the small platinum beads were made). *See also* 1550 MATR.

Σ Mathematics

Pope Sylvester II (Gerbert) imposes the Arabic numerical system on Christians, including the use of zero. *See also* 967 MATH.

♥ Medicine & health

The *Al-Quanun* ("canon of medicine"), written about this time by Avicenna, is a five-volume treatment of Greek and Arabic medicine. Translated into Latin in 1473, it dominates the teaching of medicine in Europe until the 17th century. *See also* 900 MED; 1127 MED.

☒ Tools

Gears become common in the Arab world. They are used with water wheels and water clocks. *See also* 724 TOOL; 1288 TOOL.

→ Transportation

According to chronicler William of Malmbury, Eilmer [b. c. 981, d. c. 1061], another monk from Malmesbury Abbey in England, attaches wings to his arms and legs to form a glider and launches himself from a tower. He flies some 200 m (660 ft) before crashing, perhaps because his glider was not stabilized by a tail. Eilmer is said to have broken both legs in the crash. *See also* 1877 TRAN.

1001

☒ Earth science

Following reports from Bjarni Herjolfsson, the Viking Leif Ericson sails from Greenland to the Americas where he spends the winter, probably at L'Anse aux Meadows in Newfoundland. *See also* 1009 EAR.

1005

⌚ Communication

Dar al-ilm, a science library in Cairo, Egypt, is founded. *See also* 832 COMM; 1259 COMM.



L'ANSE AUX MEADOWS The only completely authenticated European site in North America was discovered on Newfoundland in 1961. Studies of ancient Icelandic sagas indicate that this was the land known as Vinland to the Vikings. Today it has been partially reconstructed, with the sod-and-wood dwellings forming part of an interpretive museum.

1006

★ Astronomy

A supernova or “guest star” is reported in China, Japan, Europe, and the Arab lands. It remains visible for several years. Later measurements show that it was perhaps the brightest stellar event in recorded history, about halfway between the full Moon and Venus in brightness. *See also* 390 AST; 1054 AST.

1008

★ Astronomy

The *Large Astronomical Tables of al-Hakim*, or the Hakimitic Tables, named after Caliph al-Hakim, who built an important observatory, by Ibn Yunus [b. Egypt, 950, d. Egypt, 1009], contains accurate astronomical and mathematical tables based on the observations of the previous 200 years. The tables are used in later Arab astronomy. *See also* 1080 AST.

■ Construction

The Château de Josselin is built on a cliff above the Oust River in France. *See also* 796 CONS; 1173 CONS.

1009

● Earth science

Another Viking expedition attempts to found a colony at L'Anse aux Meadows in Newfoundland; the colony apparently survives for about three years. *See also* 1001 EAR; 1492 EAR.

1013

■ Construction

The al-Hakim Mosque is completed in Cairo, Egypt. Like all traditional mosques, it is modeled on Mohammed's home in Mecca, although greatly enlarged — the al-Hakim Mosque is designed to have room for half the male population of Cairo in its large interior courtyard (which contains nothing but a fountain used for washing before prayer). *See also* 691 CONS.

Alhazen (al-Hasan ibn al-Haytham)

[b. Basra (Iraq), c. 965, d. Egypt, c. 1040]

Alhazen is considered the most important of the Arab physicists and therefore the chief physicist of the early Middle Ages. His main concern was the behavior of light, which he explained better than anyone before the 17th century. When he found himself in trouble with his Egyptian ruler, he pretended to have gone mad and only gave up the pretense after the ruler had died.

1020

● Communication

Alhazen (Ibn al-Haytham) describes the camera obscura: a real image is projected into a darkened box. The image can be viewed from inside the box or can be projected onto ground glass to be seen from outside the box. Alhazen reports that he did not discover this device. *See also* 1553 COMM.

● Earth science

In *Mizan al-hikma* (“on the balance of wisdom”) Alhazen discusses how the atmosphere refracts light and uses the onset of twilight as a means to make an estimate of the height of the atmosphere.

Σ Mathematics

Alhazen solves several problems from what is now called number theory involving remainders (equivalent to congruence for numbers) and perfect numbers (a number is perfect if the sum of its factors is the number). He also writes on using lunes for squaring the circle, but may not have realized that this method will not work. *See also* 100 MATH; 1801 MATH.

❀ Physics

Alhazen determines that light travels from objects to the eye, emanating from some bodies and being reflected from others, and determines laws of reflection in curved mirrors. These laws enable him to explain correctly how lenses work and to describe focusing by parabolic mirrors, such as those used in today's reflecting telescopes. His optical work *Kitab al-manazir* (“treasury of

optics”) is influential in Europe after translation into Latin as *Opticae thesaurus Alhazeni* in 1572. *See also* 140 CE PHY; 1270 PHY.

1024

■ Construction

The castle of Fougères in northern Brittany, France, is built of red masonry. *See also* 1008 CONS; 1050 CONS.

1025

→ Transportation

A vessel wrecked off Serçe Limani, Turkey (opposite Rhodes), around this time is the earliest known evidence that seagoing wooden ships are being built in the modern way, starting with a keel and framework to which planking is added. Earlier ships were built by first joining planks together and then bracing the ship as needed. *See also* 1400 BCE TRAN; 1300 TRAN.

1030

■ Construction

A Romanesque Cathedral of Notre Dame is completed in Chartres, France, shortly before this date, built under the direction of Bishop Fulbert [b. 952 or 962, d. April 10, 1028]. The nave is not vaulted but covered with a wooden roof, which burns during this year. Two transepts are added after the fire. *See also* 561 CONS; 1134 CONS.

Σ Mathematics

Mathematician, traveler, and physicist Al-Biruni [b. Kath (Uzbekistan), September 15, 973, d. Afghanistan, December

13, 1048] writes his *History of India*, giving a general account of India's history based on a critical selection of sources. It becomes the principal introduction to Hindu numeration for the Arabs. *See also* 832 MATH.

1035

I Tools

A painting from this year shows a spinning wheel in use in China. *See also* 1280 TOOL.

1037

¶ Construction

The Abbey at Jumièges in Normandy, rebuilt starting about this time, becomes the inspiration for the Abbey of Westminster in England. *See also* 1030 CONS; 1065 CONS.

1041

↳ Communication

Sometime between 1041 and 1048 Pi Sheng, an obscure commoner in China, invents movable type. He bakes ideographs out of clay and stores the pottery characters in wooden cases according to a rhyme scheme for keeping track, since China has no alphabet. For printing, the baked ideographs are arranged in a frame embedded in a mixture of pine resin, wax, and ashes, and wedged in with slivers of bamboo. *See also* 868 COMM. 1050 COMM.

1044

◊ Materials

Tsêng Kung-Liang publishes the first recipes for three varieties of gunpowder. *See also* 850 MATR; 1267 MATR.

→ Transportation

Wu ching tsung yao ("compendium of important military techniques") by Chinese government official Tsêng Kung-Liang (a.k.a. Zeng Gung-lyang) describes magnetized iron "fish" that float in water and can be used for finding south. About this time the Chinese begin to use the compass for navigation, most likely using this device. *See also* 271 CE TOOL; 1086 EAR.

1050

↳ Communication

Some Chinese books are printed with movable type. *See also* 1041 COMM; 1440 COMM.

¶ Construction

Arundel Castle is constructed in Sussex, England. *See also* 1024 CONS; 1075 CONS.

I Tools

Indian scholar Prince Bhoja [b. 1018, d. 1060] writes *Samarangana-sutradhara*, dealing with the construction qualities of machines and automata. *See also* 850 TOOL; 1180 TOOL.

1054

★ Astronomy

The supernova that now forms the Crab nebula is observed in China, Japan, and the Arab lands; it is visible for 22 months. *See also* 1006 AST; 1754 AST.

1065

¶ Construction

English king Edward the Confessor has the Abbey of West-

minster built, the first monumental work in stone in England and the first Norman-style Romanesque building there (Edward had been raised in Normandy). The Abbey is consecrated on December 28. Rebuilt in Gothic style in 1245 by Henry III, nothing of the original Romanesque church remains today. *See also* 1037 CONS; 1245 CONS.

1066

★ Astronomy

A large comet is sighted, connected in England with the invasion by William of Normandy; today it is known as Halley's comet. *See also* 635 AST; 1456 AST.

1067

¶ Construction

The Abbey Church of Jumièges is dedicated in the presence of William the Conqueror, just returned from the conquest of England; construction had taken nearly 30 years. *See also* 1037 CONS; 1080 CONS.

1075

¶ Construction

Construction is begun under William the Conqueror on Windsor Castle, today the largest inhabited castle in Europe. *See also* 1050 CONS; 1180 CONS.

Σ Mathematics

The Persian mathematician and poet Omar Khayyám [b. Nishapur (Iran), May 15, 1048, d. Nishapur, December 4, 1131], in his *Algebra*, becomes the first to solve all types of equations with a

degree of three, also known as cubics, using a geometry-based method. *See also* 835 MATH; 1535 MATH.

I Tools

Spanish Arab Abu Ishaq al-Zarqali (known in the West as Arzachel) [b. 1028, d. 1087] about this time constructs a series of complex water clocks at Toledo (Spain), some of which show the phases of the Moon. *See also* 1088 TOOL.

1077

II Food & agriculture

Europeans reinvent the whiffletree (also known as the whippletree), a way to harness two animals — horses in Europe — to the same cart. The whiffletree had originally been developed for oxen by the Chinese in the third century CE. *See also* 200 CE FOOD.

1078

¶ Construction

About this time construction is begun under William the Conqueror of the Tower of London's White Tower; various other parts and walls are added at later dates. *See also* 1075 CONS.

1080

★ Astronomy

Abu Ishaq al-Zarqali edits the *Toledan Tables* and suggests that planetary orbits are elliptical. *See also* 1008 AST; 1609 AST.

¶ Construction

The Church of St. Semin in Toulouse, France, is built. *See also* 1067 CONS; 1088 CONS.

The other Omar Khayyám

Most people who speak English know about Omar Khayyám. They recall that he wrote about “a jug of wine, a loaf of bread, and Thou.” In fact, he did not. That was Edward FitzGerald, a 19th-century English poet whose translation of Omar was so loose that most scholars consider the FitzGerald poetry as a separate work.

Omar was a great poet himself, as readers of Persian attest. But he is also the mathematician who solved the general cubic equation of the third degree hundreds of years before Tartaglia, the 16th-century mathematician generally given credit for the feat. Omar’s method for solving the cubic did have some limitations, however. It was completely geometrical and so produced only positive roots (a line segment cannot have negative length).

Omar’s work was also a step toward the unification of algebra and geometry that came in the 17th century with Descartes and Fermat. Omar pointed out that algebra is not just a collection of tricks for obtaining an answer, but a science deeply related to geometry. Despite this, he believed that it would be impossible to solve the cubic with purely algebraic means. Because of his commitment to geometrical methods, Omar also believed that equations of degrees greater than the third do not describe reality in any way, since observable space has three dimensions only.

In addition to his mathematical work, Omar also contributed to astronomy. His greatest feat as an astronomer was the reform of the Islamic calendar so that it would keep good time with the heavens.



THE TOWER OF LONDON The White Tower is the original part of the Tower of London, a complex of buildings within a stout wall that sits on the Thames in London. Today it is one of the great tourist attractions of England, but it remains best known for the prisoners and beheadings that took place in the Tower over much of the span of English history.

1085

Communication

Alfonso IV of Castile takes Toledo, Spain, an important center of learning, from the Arabs. One consequence is that Christian scholars begin to learn about Arab science. *See also* 900 MED; 1130 MED.

1086

Earth science

Dream Pool Essays by Chinese scientist Shen Kua [b. Chekiang, China, 1031, d. Ching-K'ou, China, 1095] contains the first known reference to the use of a magnetic compass for navigation and outlines the principles of erosion, uplift, and sedimentation that are the foundation of

earth science. *See also* 1044 TRAN; 1117 TRAN.

Energy

The Domesday Book, a survey of England ordered by William the Conqueror, lists 5624 water wheel-driven mills in England south of Trent. There are 268,984 persons actually counted in the survey, but not everyone in England is counted as the project is not completed. The total population of England at this time is thought to be about 1,500,000, giving 1 mill per 300 persons. *See also* 25 BCE ENER; 1323 ENER.

1088

Construction

The Benedictine Abbey Church at Cluny is started; it

will be the largest church on Earth until St. Peter's in Rome is consecrated. *See also* 1080 CONS; 1626 CONS.

Tools

In China, Su Sung builds a giant water clock, orrery, and mechanical armillary sphere between this date and 1092. Ten m (35 ft) tall, it is considered the finest mechanical achievement of the time. A constant flow of water turns escapement wheels that are geared to power the clock and orrery (a mechanical representation of the heavens, somewhat like a planetarium), while the armillary sphere is available for use in checking the accuracy of both the clock and orrery by observing the Sun and planets. *See also* 724 TOOL; 1364 TOOL.

1097

Construction

The last of the *aulae regis*, or great halls of medieval England, is Westminster Hall in London, the largest in Europe. The walls are built starting this year as part of a reconstruction of the Palace of Westminster. The hall is not to be confused with Westminster Abbey, a cathedral started in 1045. Westminster Hall is 88 m (290 ft) long and 20.5 m (67.5 ft) wide. The hall still stands today despite shoddy construction by masons just learning their craft. *See also* 1075 CONS; 1399 CONS.

Water for power

In the history of technology, waterpower has a surprisingly long career. Developed in Antiquity, the water wheel became the main source of power during the Middle Ages and remained so until the 19th century, when it was replaced by the steam engine. Waterpower still plays an important role today in many countries, where it is used for generating electricity, although the water wheel has now been replaced by the much more efficient water turbine.

The main application of waterpower for centuries was the grist mill, which grinds grain into flour. Water mills appeared throughout the Roman Empire during the third and fourth centuries, but the fall of the Roman empire prevented their widespread use in later centuries.

Much of the technology of water wheels from the Roman and the Hellenistic civilizations was taken over and perfected in the Islamic world. Several of their types of irrigation systems were powered by water wheels. In Europe, water wheels came into widespread use only during the tenth century. The Domesday Book (eleventh century) lists 5624 water mills in England, which corresponds to about one water mill per 300 inhabitants.

The early water wheels were mainly of the undershot type;

water passed under the wheel, driving the lower paddles. Undershot wheels are easy to install and they appeared in many locations on rivers and streams. Many of these water mills were mounted on barges, making their operation independent of the water level of the river. This type of floating mill was first invented by the Roman general Belisarius in 537. He installed floating mills on the Tiber when the Goths, besieging Rome, had cut the city's water supplies. In cities it was preferable to install floating mills under bridges because of the faster flow of water between the arches. The number of water mills built under bridges in Paris was so great at one time that they seriously impeded boat traffic on the Seine.

During the late Middle Ages, water wheels became the power source for a wider range of applications, including pumps, hammers, grinding wheels, saws, and lathes.

The overshot wheel also appeared in the late Middle Ages. Overshot wheels are more efficient because they use more energy in the flow of water. Their efficiency was further increased by replacing the paddles by buckets, whereby the weight of water collected in buckets adds to the driving force acting on the wheel. John Smeaton calculated in the 18th century that an undershot wheel uses 22 percent of the energy in the flow of water, while an overshot wheel uses 63 percent.

1100

★ Astronomy

Chinese astronomers build a stone planisphere of the heavens that correctly demonstrates the cause of solar and lunar eclipses. A planisphere is a device that shows a map of the heavens for whatever date and time it is set. *See also* 510 CE AST.

■ Construction

The Anasazi of Chaco Canyon (New Mexico) construct the building we know today as Pueblo Bonito, with 800 rooms that could be home to as many as 1000 people. As an apartment house, it is not to be surpassed in size until a large apartment complex is built in New York City in 1882. *See also* 800 CONS; 1882 CONS.

■ Food & agriculture

Forks for dining reach Italy from the Middle East, the first inroads of the implement into Europe. *See also* 600 FOOD; 1370 FOOD.

Italians learn to distill wine to make brandy. *See also* 900 FOOD; 1276 FOOD.

◊ Materials

The art of paper manufacture spreads from Cairo to Morocco. *See also* 900 MATR; 1150 MATR.

Iron production in China reaches an annual level of 170,000 metric tons (154,000 short tons). *See also* 954 MATR; 1340 MATR.

During the Song dynasty in China, true porcelain pottery is made, along with improved glazed stoneware called celadon. *See also* 800 MATR; 1375 MATR.

I Tools

The gravity-powered catapult, in which the principle of the lever is used to give great speed to a missile attached to the long arm of the catapult when a heavy weight brings down the short arm, is invented. The new catapult is more reliable than the torsion-powered catapult, in use for about 1400 years, since the new form is not affected by humidity. *See also* 100 CE TOOL.

1101

Σ Mathematics

Henry I of England introduces a measure of length equal to the length of his arm — the yard. *See also* 1215 COMM.

1104

■ Construction

The earliest pointed arch, or ogive, on a cathedral is used in the Romanesque Cathedral of Durham. *See also* 561 CONS; 1122 CONS.



DURHAM CATHEDRAL The pointed ogive arches on Durham Cathedral tend to be closer to the older, semicircular arches, showing the transition from one type to the other. Many of the arches on the cathedral continue to use the older style.

1105

⌚ Communication

Woodcuts are used in Europe for block printing capital letters. *See also* 868 COMM; 1298 COMM.

■ Construction

The Chinese build a pagoda 28 m (78 ft) high from cast iron, each level cast as a single piece. *See also* 954 MATR.

King Kyanzittha [reigned 1084–1113] of Pagan (Burma) completes construction of Ananda Temple, which was started in 1091. It is considered one of the finest Buddhist pagoda-temples of the period. *See also* 1113 CONS.

⚡ Energy

The Papal Bull of 1105 mentions windmills in Europe for the first time. It grants a concession to the Abbot of Savigny to build windmills in the French dioceses of Bayeux, Coutances, and Evreux. *See also* 600 ENER; 1185 ENER.

1107

◊ Materials

The Chinese invent multicolor printing; they introduce banknotes printed in six colors, mainly to make early paper money harder to counterfeit. *See also* 900 MATR; 1457 COMM.

scientific topics Adelard has learned from the Arabs — meteorology, optics, acoustics, and botany. About this time Adelard also writes *Rules of the Abacus* and *Usage of the Astrolabium*. *See also* 1020 COMM; 1126 AST.

1113

■ Construction

King Suryavarman II of Khmer (Cambodia) comes to the throne. His regime sees the beginning of construction of the great temple complex of Angkor Wat, requiring eventually an estimated 350,000,000 m³ (455,000,000 cu yd) of building material transported to the forest site by rafts. The completed temple itself covers over 120 hectares (300 acres) and is part of a much larger temple complex. *See also* 1105 CONS.



1111

⌚ Communication

Questiones naturales by Adelard of Bath [b. Bath, England, c. 1090, d. c. 1150] is an early attempt at scientific method and covers some of the sci-

ence of the day. The intricate temple complex at Angkor Wat in Cambodia has been under siege by the surrounding jungle practically from its initial construction. During times of peace and prosperity, the trees and vegetation are cleared away, but the overgrowth returns whenever Cambodia is impoverished or in a state of turmoil.

1116

→ Transportation

The first European stanch, a predecessor of the lock, is thought to have been installed on the river Scarpe in Flanders. A stanch is a gate placed in a weir (a dam used for rais-

ing water level, for example, for a water wheel) that can allow boats to pass over it. See also 1198 TRAN.

1117

→ Transportation

Chu Yü's *P'ingchow Table Talk* contains the first mention in Chinese literature of a compass used for navigation at sea. See also 1086 EAR; 1190 TRAN.

1121

■ Construction

Reginald of Châtillon, one of the Crusaders, builds the giant castle-fortress of Al-Karak (Kerak) near the Arabian frontier in what is now Jordan. See also 1075 CONS; 1180 CONS.

Cathedrals

Building technology during the early Middle Ages in Europe lagged behind that of the Romans, the Muslim peoples, and the Chinese. But a technical revolution in construction took place during the years 1100–1270 in northern Europe, especially England and France. During that period, a number of cathedrals of exceptional size and height were constructed in several cities.

To achieve these stunning dimensions, particularly noticeable in the spacious interiors, the cathedral builders employed three technical innovations: the ribbed vault, the pointed arch, and the flying buttress. These three elements were first used together at the cathedral at Durham, England — although at Durham the ribbed vaults were essential to the first design and the pointed arch was not added until over a quarter of a century later.

A vault is, so to speak, the three-dimensional equivalent of the two-dimensional arch. It is ribbed if it is provided with independent arches for stronger supports. The main purpose of a stone vault in a cathedral is to protect the building from fire by isolating the timber roof from the rest of the building. The vault also has an aesthetic function, giving the interior a soaring appearance in contrast to that of a flat, wooden ceiling.

Structurally, the vault at Durham, and in later churches, was made self-supporting by a system of diagonal and transversal ribs. Because of their pointed shape, these deflect sideways vertical pressure caused by the weight of the vault. The ribs were constructed first, and the space in between the ribs was then filled in. The ribs had, besides their structural function, an aesthetic function. They branch out from the top of the piers, giving the whole structure a unified look.

Because the ribs supporting the vault translated a vertical force into a transversal force, pushing the piers and supporting walls outward, the builders had to find a way to neutralize this force. They achieved this by building "flying buttresses" that in subsequent years would become the most remarkable feature in cathedrals throughout Europe. These were additional walls on the outside that were perpendicular to the walls of the vault.

The basic structure of the Durham cathedral was replicated shortly afterward in a number of cathedrals in Europe. Religious fervor, but also competition between cities, pushed toward ever higher structures. In France, the "Cathedral Crusade" was sparked by Suger, the abbot of the great monastery at Denis, near Paris. He was the main designer for the rebuilding of the church at St. Denis, which was completed in 1144. His friend, Bishop Henry of Sens, built the cathedral at Sens, which was completed in 1160. Both church buildings incorporated the three new elements of Durham Cathedral, but the structures were far lighter and less massive than those of Durham Cathedral. William of Sens went in 1174 to England where he rebuilt the Cathedral of Canterbury along the lines of the Cathedral of Sens.

Subsequently, the role of the flying buttresses, which became more complex structures, became more important in that they took over most of the support of the vault, allowing the replacement of the side walls by huge windows. The Notre Dame Cathedral in Paris, on which construction was started in the 1160s, is one of the examples of this new trend.

The vault of the Notre Dame, at 33.5 m (110 ft), was higher than anything built before. Soon an element of competition between cities came to the fore, and cathedrals with even higher vaults were built. The Chartres Cathedral has a vault at the same height as the Notre Dame, but the vaults at Rouen and Reims are 38 m (125 ft), the vault of Amiens Cathedral is 42.5 m (140 ft), and that of Beauvais is nearly 49 m (157 ft).

The cathedrals at Beauvais and at Cologne are the best examples of Gothic architecture in its most perfected form. All the walls are replaced by huge expanses of stained glass, the whole structure being supported by a complex system of buttresses at the outside. In France alone, about 80 cathedrals were built between 1150 and 1280. Later the cathedral fever abated. Mainly because of the huge costs and the loss of population from the plague of the 14th century, many of the cathedrals were left unfinished. The construction of some of them — Cologne is an example — was not completed until the 19th century.

Wind power

Sailboats are probably the oldest form of wind power, and it is likely that the sail inspired the first builders of windmills. Wind power that provides rotary motion is a more recent invention than waterpower. Some historians believe that the first windmills appeared in the Greek islands at the beginning of the Christian era, but a firm proof of this has yet to be found. During the seventh century windmills probably appeared in areas with no flowing water, such as the western part of Afghanistan. Early windmills consisted of a rotor turning on a vertical axis to which were attached curved sails made of fabric. The wind was admitted through funnel shaped openings facing the direction of the wind. Because no gears were required for driving the millstone, losses from friction were minimal. By the tenth century such mills were generally used throughout the Arab world.

Windmills were also in use during that time in Iran and in China, where they were used for irrigation and land drainage.

In Europe the windmill appeared about 1100. These windmills had horizontal axes or windshafts that had to be placed in the direction of the wind. The first type used was the postmill: The entire mill, including the millstones, was mounted on a fixed

foundation, or "post," on which it could rotate. A second type of mill, the tower mill, appeared at the end of the 14th century. Only the top cap, housing the windshaft, of a tower mill rotates. In some later types of tower mills, an auxiliary windshaft with blades placed parallel to the main windshaft automatically rotates the top cap into the required position.

Windmills in Europe were first used for milling grain, but soon their use widened to include many other activities; for example, sawmills and mills were used for crushing ores. In Holland, one very important application was pumping water for the reclaiming of land. The first windmill in Holland started pumping in 1414. Windmills drove both Archimedean screws and water wheels for pumping water. Those equipped with water wheels could pump water up only a few feet and therefore several windmills in succession were required to pump water to greater heights. At one time, 7500 windmills were in use in Holland for pumping water and for industrial applications. Their success was so great that even in the 18th century John Smeaton considered increasing the use of windmills in England. In 1759 Smeaton investigated the performance of windmills by building models, but eventually concluded that they could not compete with the more powerful steam engines then in use.

1122

Communication

Sic et non ("yes and no") by French scholar Peter Abelard [b. Le Pallet, Brittany, France, 1079, d. Chalon-sur-Saône, April 21, 1142] is a collection of contradictory statements found in the writings of various authorities, demonstrating that authority is of no use and that reason and logic are needed to solve problems. See also 1230 MATH.

Construction

The first cross-ribbed vault still in existence is built over the ambulatory at Morienval Cathedral (France). See also 1104 CONS; 1129 CONS.

1126

Astronomy

Adelard of Bath translates *Astronomical Tables* by Al-

Khwarizmi from the Arabic. About this time he also translates Al-Khwarizmi's *Liber ysagogarum alchorismi* ("introduction of algorism"), a work about arithmetic. See also 1111 AST; 1142 MATH.

Tools

The first artesian well in Europe is drilled. In China, artesian wells are known before the common era.

1127

Medicine & health

Stephen of Antioch translates the medical encyclopedia *Kamil al-sina'ah al-tibbiyah* ("complete book of the medical art") by Persian physician Ali ibn al-'Abbas al-Majusi (a.k.a. Haly Abbas) [fl. 940–80] into Latin as *Liber regius* ("the royal book"). See also 1000 MED; 1130 MED.

1129

Construction

Abbé Suger [b. Flanders or St. Denis, France, or Toury, France, c. 1081, d. St. Denis, January 31, 1151] starts construction on the first portion of the Abbey Church of St. Denis (St. Denis, France), which will become the first Gothic church with flying buttresses. See also 1122 CONS; 1140 CONS.

1130

Construction

About this time the influence of the Cluniac Order on style, featuring wavy curves and ornamentations and exemplified by the cathedrals of Riems and Winchester, is replaced in Europe by the Cistercian style, favoring straight lines and right angles, with serenity and balance as primary goals. See also 1147 CONS.

The new choir of Canterbury Cathedral in England, one of the architectural masterpieces of its time, is dedicated. See also 1104 CONS; 1134 CONS.

Archbishop Henry, the Boar, begins the Cathedral of Sens (France). It will become the first large Gothic cathedral. See also 1129 CONS; 1140 CONS.

Medicine & health

Scholars in Toledo begin translating the works of Arabic scientist Avicenna into Latin; these cover almost every aspect of health and medicine. See also 1000 MED; 1473 MED.

1134

Construction

A fire in the Romanesque cathedral built by Bishop Fulbert at Chartres is an immediate stimulus for building new towers at Chartres Cathedral

1134–1139

(officially the Cathedral of Notre Dame at Chartres, France). The northern tower is started this year and the Royal Portal and southern tower begin a few years later. By 1145 both towers are in progress and have inspired the local population to work toward a new building. *See also* 1030 CONS; 1164 CONS.

1139

■ Construction

The harbor lighthouse at Genoa (Italy) is built this year or in 1161; Christopher Columbus's uncle Antonio Colombo becomes the lighthouse keeper in 1449, but the light does not survive into the present. *See also* 40 CE CONS; 1157 CONS.

1140

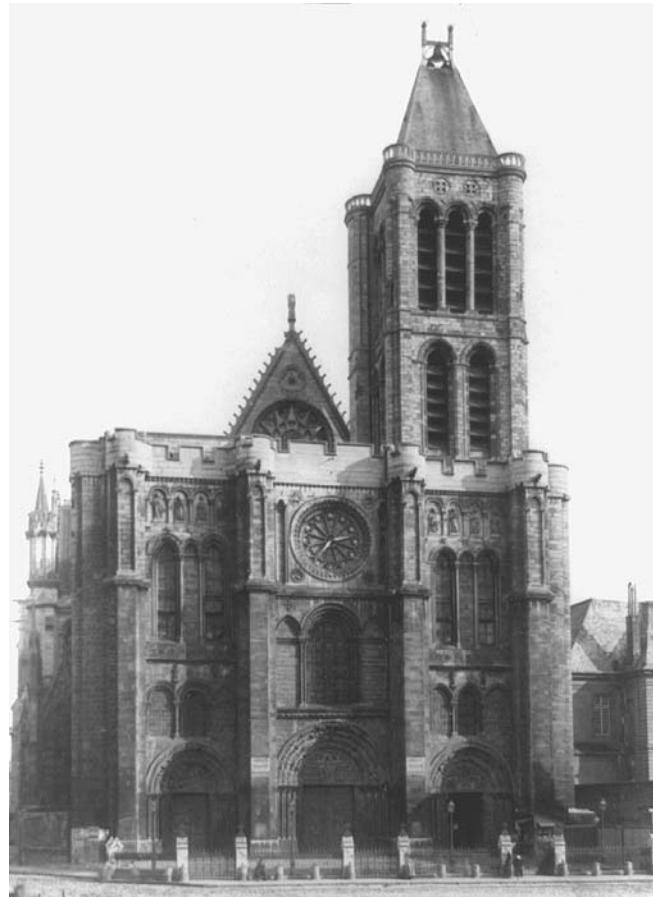
■ Construction

The cathedral of San Ruffino is built in Italy. *See also* 1030 CONS; 1163 CONS.

Abbé Suger embarks on one of the epoch-making buildings in the history of architecture, the choir portion of the Abbey Church of St. Denis, completed and consecrated in 1144. This new Gothic style is possibly influenced by Neoplatonic thought from the school of Chartres, where architecture is viewed as applied geometry. *See also* 1134 CONS; 1194 CONS.

♥ Medicine & health

The Norman king Roger II decrees that only physicians with a license from the government are allowed to practice medicine.



ABBEY CHURCH OF ST. DENIS Also known as the Cathedral of St. Denis, the Abbey Church is on the outskirts of Paris. Its construction marks the transition from the previous Romanesque style of cathedral to the Gothic.

1142

Σ Mathematics

Adelard of Bath translates Euclid's *Elements* (15 books, of which 13 are now believed to be genuine) from the Arabic. *See also* 1126 AST; 1175 AST.

1145

Σ Mathematics

Robert of Chester translates Al-Khwarizmi's *Algebra* from Arabic into Latin. *See also* 835 MATH.

1147

■ Construction

The best surviving example of early Cistercian architecture, the Abbey of Fontenay, begun in 1130, is completed. It emphasizes the "perfect" ratio of one to two espoused earlier by St. Augustine. The abbey may have been designed by Bernard of Clairvaux, leader of the Cistercian movement. *See also* 1130 CONS.

1150

❖ Materials

The art of paper manufacture spreads to Spain from Morocco. *See also* 1100 MATR; 1277 MATR.

Potters in Persia (Iran), with the aid of potters from Egypt, develop a new low-fired pottery resembling soft-paste porcelain, but based on powdered silica sand, frit, and white clay. The pottery is used as a base and painted with luster glazes. *See also* 1100 MATR; 1616 MATR.

Σ Mathematics

Siddhanta siromani ("head jewel of an astronomical system") by Bhaskara (a.k.a. Bhaskara II) [b. Vijayapura, India, 1114, d. Ujjain, India, 1185] summarizes the arithmetic and algebraic knowledge in India of the time, focusing on solving Diophantine equations. *See also* 250 CE MATH; 1225 MATH.

♥ Medicine & health

The book *Regimen sanitatis salernitatum* ("the Salerno health diet") is written at the Salerno school of medicine. It becomes a best-selling health guide for the Middle Ages. *See also* 1130 MED; 1185 MED.

Trotula of Salerno [b. c. 1097] advocates cleanliness, a balanced diet, exercise, and avoidance of stress for maintaining health. Her *Passionibus mulierum curandorum* ("the diseases of women") deals with the medical needs of women. *See also* 900 MED.

❖ Physics

Bhaskara describes a wheel that he claims would run

Perpetual motion: an old dream

Since Antiquity humans have been fascinated by the motion of the stars in the celestial sphere. They hoped to imitate this motion and build a machine that would run forever without using an external force, such as wind or flowing water. Many believed that rotation is an intrinsic property of the wheel. Even the Polish astronomer Copernicus believed that anything round — according to him the perfect shape — would rotate by itself.

One of the early attempts to build a perpetually turning wheel can be found in a Sanskrit manuscript of the fifth century. It describes a wheel with sealed cavities in which mercury would flow in such a fashion that one half of the wheel would always be heavier than the other half; supposedly this would keep the wheel running. Around 1235 the French architect Villard de Honnecourt devised a wheel based on a similar principle. An odd number of hammers pivot around their attachment points on the wheel. Because one half of the wheel always has a larger number of hammers than the other half, the wheel would keep turning. These devices existed in theory only, since any actual machine of this type fails to operate.

It was during the Renaissance that engineers became seriously

interested in building a machine that would produce power continuously. They were inspired by the large number of windmills and water wheels that were then in use. The concepts were simple: A water wheel drives a pump that continuously pumps up the water that runs the wheel into an elevated reservoir, or a windmill actuates giant bellows that drive the windmill.

Many other designs made their appearance. Some were systems in which water would keep flowing endlessly. Others were complicated mechanisms. In one type, steel balls roll down an inclined plane. The inclined plane pivots when the ball reaches its end. This motion then actuates a mechanism that brings the ball back to its beginning position on the inclined plane.

The first to formulate precisely why such perpetual-motion machines could not work was Gottfried Wilhelm Leibniz, who in his "Essay on Dynamics" stated that energy could not be created out of nothing. Although Leibniz's idea was not paid much attention, by the end of the 18th century most scientists had concluded that perpetual-motion machines could not work. The Paris Academy decided to reject any proposals for perpetual-motion machines. All such devices neglect the loss of power to friction within the parts and often other factors that prevent functioning. Notwithstanding, inventors continue to propose perpetual-motion machines right up to present.

indefinitely, one of the first descriptions of a supposed perpetual motion machine. *See also* 1235 TOOL.

Transportation

The Chinese develop the first rockets. *See also* 1044 MATR; 1380 TRAN.

1154

Medicine & health

Sultan Nour Al-Din Zinki builds a bimaristan, or hospital, in Damascus (Syria), which also functions as a school of medicine. *See also* 707 MED; 1284 MED.

Physics

Eugenius of Palermo translates Ptolemy's *Optics* from Arabic into Latin. *See also* 140 CE PHY; 1270 PHY.

1155

Communication

A map of western China is printed in China. It is the oldest known printed map. *See also* 116 CE COMM; 1492 COMM.

1156

Earth science

Henricus Aristippus translates Aristotle's *Meteora* (a.k.a. *Meteorologica*) from Greek into Latin. *See also* 910 COMM.

1157

Construction

The light tower at Meloria (Italy) is often considered the first lighthouse in Europe since Roman times, although the lighthouse at Genoa, also

built around this time, may have preceded it. In any case, lighthouses are being erected all along the Italian coast in the twelfth century, including towers at Venice, Tino, and one near the Straits of Messina. *See also* 1139 CONS; 1304 CONS.

1158

Communication

The University of Bologna (Italy) is founded. *See also* 900 MED; 1167 COMM.

1160

Communication

Arabian philosopher Averroës (Abu-Al-Walid Muhammad ibn Ahmad ibn Rushd) [b. Cordoba, Spain, 1126, d. Marrakesh, Morocco, December 10, 1198] about this time

writes lengthy commentaries on the works of Aristotle that will become a major influence in Europe in the Middle Ages. *See also* 1156 EAR.

Construction

The earliest surviving engineering plan for a building's water supply system is a drawing of the plans for Christ Church in Canterbury, built about this date. The plan shows water lines from outside in red and a separate system for handling rainwater in yellow, with tanks used to settle the water and hold it for eventual use by varied parts of the church, including the latrines. Outside water is siphoned into a main tank in the tower. *See also* 2300 BCE CONS; 1600 TOOL.

1163

■ Construction

The cornerstone of the Cathedral of Notre Dame in Paris is laid. *See also* 1030 CONS; 1220 CONS.

1164

■ Construction

Although the exact date of completion of the western facade of Chartres Cathedral is uncertain, the south tower is finished about this date and the rest of the Royal Portal is probably complete by 1175. *See also* 1134 CONS; 1194 CONS.

1167

■ Communication

Oxford University is founded in England this year or 1168, although there may have been lectures at Oxford as early as 1133. *See also* 1158 COMM; 1170 COMM.

1170

■ Communication

The University of Paris (France) is founded as a definite entity before this date, although its seeds go back to the early 1100s. *See also* 1167 COMM; 1210 COMM.

1173

■ Construction

The Château de Josselin is rebuilt after damage in a war between France and England. *See also* 1008 CONS.

1175

★ Astronomy

Gerard of Cremona [b. Cremona (Italy), c. 1114, d. Toledo, Spain, 1187] translates the *Almagest* from the Arabic into Latin. Around this time he also translates from Arabic works by al-Kindi, Thabit ibn Qurra, Rhazes, al-Farabi, pseudo-Aristotle, Avicenna, Hippocrates, Aristotle, Euclid, Archimedes, Diocles, and

Alexander of Aphrodisias. *See also* 140 CE AST.

1176

■ Construction

The original form of the stone London Bridge, known today as Old London Bridge, is started by English priest and architect Peter Colechurch. After it is completed in 1209, various people begin to build houses on it, ruining what little structural integrity the bridge has (there are 19 arches of different sizes and a drawbridge). The houses, many three or four stories high, cause the bridge to continually lose pieces, as in the nursery song. In the 1820s Old London Bridge is replaced by a more modern version, which itself is replaced in the 20th century by the present bridge. *See also* 1831 CONS.

I Tools

A document mentions a clock in the Cathedral of Sens (France). *See also* 1130 CONS; 1292 TOOL.

1178

■ Construction

According to tradition, Saint Bénezét starts construction of the Pont de Avignon (Avignon bridge), probably copied in design from the nearby Roman Pont du Gard aqueduct bridge. The bridge is supposedly completed in 1188, but it was rebuilt in the 14th century and details of the early design and history are clouded. *See also* 19 BCE CONS; 1192 CONS.

1180

■ Construction

The ancient castle at Dover, which may date to Roman times with various Saxon expansions, is rebuilt with massive stone walls and turrets. Although subsequently altered in various ways in several wars, the stone castle erected at this time is essentially the one we see today. *See also* 1075 CONS; 1284 CONS.



DOVER CASTLE A heavily fortified complex on the part of England nearest the continent of Europe, Dover Castle could be the archetype of a castle, with its thick stone walls and tiny openings for archers to use in fighting off the enemy.

I Tools

Ibn Ismail Ibn al Razzaz al-Jazari [b. c. 1150] about this time writes a treatise on automata, *Kitab fi ma'rifat al-hiyal al-handasiyya* ("the science of ingenious mechanisms"). Among several designs for clocks it contains the description of one that keeps time by the loss of weight of a burning candle. *See also* 1088 TOOL; 1288 TOOL.

→ Transportation

The oldest Western evidence for the use of a stern-mounted center rudder is in carvings made about this time. *See also* 1190 TRAN.

1181

★ Astronomy

A supernova is reported in China and Japan. It remains visible for 183 days. *See also* 1054 AST; 2002 AST.

1184

→ Transportation

King Louis Philippe of France orders the roads of Paris paved for the first time; the paving is done with stones each about 18 cm (7 in.) thick and 50 to 132 cm (20 to 52 in.) long. *See also* 170 BCE TRAN.

1185

↗ Energy

Shortly before this date windmills with horizontal axes begin to be built in the North Sea region. The windmills referred to in the Papal Bull of 1105 were also probably of this type, since there is no evidence that windmills of the

Persian type, with vertical axes, ever reach Europe. *See also* 1105 ENER.

♥ Medicine & health

Burgundio of Pisa [d. Pisa (Italy), 1193] translates various treatises by Galen from Greek into Latin. *See also* 170 CE MED.

1189

❖ Materials

A paper mill is established in Hérault, France; it is probably the first in Europe. *See also* 1150 MATR; 1277 MATR.

1190

⌚ Communication

Guide for the Perplexed by Jewish philosopher and physician Moses Maimonides (Hebrew: Moses ben Maimon) [b. Cordoba, Spain, March 30, 1135, d. Cairo, Egypt, December 13, 1204] is his attempt to reconcile Aristotle's ideas with the Old Testament. *See also* 1295 COMM.

❖ Food & agriculture

The oldest known depiction of a fishing reel is made in China. *See also* 7500 BCE MATR; 1410 FOOD.

→ Transportation

De naturis rerum ("on natural things") by Alexander Neckam [b. St. Albans, England, September 8, 1157, d. Kempsey, Worcestershire, England, 1217], written about this time, contains the first known Western reference to the magnetic compass. *See also* 1576 TRAN.

The sternpost rudder, possibly borrowed from the Chinese, replaces on most boats the

steering oars that have been used in Europe and the Near East since Antiquity. *See also* 1180 TRAN.

1192

■ Construction

The Marco Polo Bridge, or Lugou Qiao, across the Yongding River near Beijing, started in 1189, is completed. Made from huge granite blocks with carved stone lions, and 235 m (700 ft) long, the bridge is still heavily used by bus and truck traffic. The English name comes from a remark in Marco Polo's diary calling it "a very fine stonebridge . . . that has few equals in the world." *See also* 1178 CONS.

1194

■ Construction

On the night of June 10–11, a great fire destroys most of the town of Chartres and the entire cathedral except for the west façade. The people of the village immediately decide to rebuild the cathedral and work is started on a new design for the church incorporating many mathematical relationships based on the Golden Ratio and other mystical ideas. *See also* 1164 CONS; 1220 CONS.

1197

■ Construction

Richard the Lion-Hearted [b. Oxford, England, September 8, 1157, d. Chalus, France, April 6, 1199] builds the Château Gaillard Castle on a hill overlooking the Seine in Normandy, France. *See also* 1024 CONS; 1200 CONS.

1198

→ Transportation

The first documented European stanch, considered a predecessor of the lock, is installed over a ten-year period on the river Micio in Italy. A lock, or pound lock, is essentially two stanches placed close together so that one can be opened to let water in, then closed while the other is opened to let water out. In the process, a boat can move up or down with the water level more easily than over a stanch, for a stanch amounts to an artificial rapids. *See also* 1116 TRAN; 1373 TRAN.

1200

★ Astronomy

The Chinese build an observatory that allows them to calculate with high precision the length of the year by measuring shadows projected on the ground. *See also* 1000 AST; 1400 AST.

■ Construction

A chronicler of about this time reports that the Romanesque transept tower of the Beverley Minster has collapsed. He blames this on the architects' having sacrificed a strong structure to achieve an artistic effect. *See also* 1284 CONS.

The administration of land drainage in the Low Countries (primarily what is now the Netherlands) becomes invested in a central organization known as the *Hoogheemraadschap*, or Main Polder Boards. *See also* 1556 FOOD.

At Mesa Verde (southern Colorado), the Anasazi build pueblos in the face of large cliffs — probably for defensive purposes. These survive fairly well today, protected by the overhang of the cliffs, but they are not as well built as earlier pueblos, such as those at Chaco Canyon (New Mexico), which date from 100 to 200 years earlier. *See also* 1100 CONS.

About this time the original version of Kalmarhus, or Kalmar Castle, an island fortress, is erected in Sweden. It is rebuilt and expanded in the 16th and 17th centuries, although part of the 13th-century castle still remains. *See also* 1197 CONS; 1222 CONS.

Energy

Coal mines are operating in pits in Great Britain on the

Firth of Forth, near Edinburgh, Scotland, and in Northumberland. *See also* 1307 ECOL.

Houses with chimneys gradually become common, although chimneys had been in use earlier for bakers' ovens and for smelting.

Food & agriculture

Buckwheat is grown in Europe.

Materials

The Catalan forge emerges in Catalonia, Spain, for smelting iron. Using a column of falling water to push air into the mixture of iron ore and burning charcoal, the forge is now considered a predecessor to the blast furnace. The resulting iron is used as the basis for wrought iron. *See also* 800 MATR; 1340 MATR.

1202

Mathematics

Liber abaci by Italian mathematician Fibonacci, or Leonard of Pisa, introduces zero to Europe and, in a problem about the reproduction of rabbits, the sequence of numbers known as the Fibonacci sequence: 1, 1, 2, 3, 5, 8, 13, 21, . . . , for which each new number is found by adding the two preceding numbers. The sequence reappears throughout mathematics and nature, in such unlikely places as the pattern of seeds on a sunflower or leaves on an herb and is connected to the Golden Ratio (the limit of ratios of adjoining members), a ratio of length to width favored by artists and architects. *See also* 1220 MATH.

Leonardo Pisano known as Fibonacci (a.k.a. Leonard of Pisa)

[b. Pisa, Italy, c. 1180, d. c. 1250]

Fibonacci ("son of Bonaccio") traveled to North Africa as a young man and became acquainted with Arab mathematics, including the Hindu-Arabic decimal system of numeration. His oddly named *Liber abaci* ("book of the abacus"), which had little to do with the abacus, is devoted to explaining the virtues of this form of numeration and to presenting ideas of algebra. His other books explored equations, irrational numbers, Diophantine equations, and geometry. He frequently solved geometric problems with algebra.

1206

Tools

Ibn Ismail Ibn al Razzaz al-Jazari publishes his *Al-jami'*

Water for control

Before the 20th century, factories with many different machines used belts to transfer energy from a central power source, often a water wheel. With the advent of electricity, it was possible to transfer an electric current by wire and with an electric motor have power dispersed, with each machine having its own motor. In the late 20th century, the advent of computer chips dispersed not only power to different machines, but also control, first in "fly-by-wire" aircraft and later in other devices. The advent of wireless systems for computers may lead to yet another revolution. But before computer chips, electricity, and even before the use of belts, clever engineers found ways to disperse power and control machines using water alone. One of these from the Middle Ages was Ibn al Razzaz al-Jazari.

His works describe several types of machines for lifting and pumping water as well as several types of water clocks, some that he invented and some the creations of other engineers. He is thought to have invented the *saqiya*, a mechanism for lifting

water that consists of a chain with pots attached to it driven by a water wheel. Once water is lifted to a height, it can be used to produce additional power by flowing downward under the force of gravity. Hundreds of years later, when the first steam engines were invented for pumping water from mines, one of the first ways that a steam engine was used to turn a wheel was based on his principle. The steam engine raised water, which then flowed down a chute to turn a water wheel.

Al-Jazari developed devices powered by water draining through a small hole. The force of flowing water through the hole changes with the amount of water remaining in the vessel. In one design, al-Jazari kept this flow constant by using a conical valve mounted on a float in a smaller vessel. If this smaller container filled too fast, the valve closed the hole, stopping the flow. The speed of the machinery powered by the flow could be adjusted by rotating a drum with a small hole in the side through which water escaped from the smaller container. Manually turning the drum so that the hole moved to a lower position increased the flow of water and therefore the speed of the entire operation.

bain al-lim wal-amal al-nafi fi sinat'at al-hiyal ("treatise on the theory and practice of the mechanical arts"), which gives descriptions of automata and clepsydras, as well as a piston suction pump and a crank connecting-rod system that turns rotary motion into up-and-down motion. See also 1180 TOOL; 1296 MATR.

1209

Σ Mathematics

In Damascus Sharaf al-Din al-Tusi [b. Tus, Klurasan (Iran), 1135, d. (Iran), c. 1213] writes *Treatise on Equations*, which describes how to solve various types of cubic equations, including a use of the discriminant (a number that reveals the nature of the solutions to a quadratic equation) and Horner's rule for approximating the solution to any algebraic equation. See also 1075 MATH; 1245 MATH.

→ Transportation

The first major canal to be built in the West since Roman times is the Ticinello, built to carry water 26 km (16 mi) from the Ticino River to Milan (Italy), where the water is used for irrigation and to fill a moat. Later, as the Milanese realize its value in navigation, the canal is enlarged and renamed the Naviglio Grande (Grand Canal). Its waters are also used for fish weirs (permanent nets across the canal used to catch fish), to the detriment of navigability. See also 1387 TRAN.

1210

↳ Communication

The teaching of Aristotle's

works is forbidden at the University of Paris since they might undermine Christianity. See also 1170 COMM; 1217 AST.

I Tools

Sharaf al-Din al-Tusi invents the linear astrolabe, a simple device based on a marked rod, a plumb line, and a cord. Although not equal in precision to a regular astrolabe, it is simple to construct and use. See also 200 BCE AST; 1391 TOOL.

1215

↳ Communication

English barons in June force their king, John, to sign the oath known as the Magna Carta, the basis of English law to this day. In addition to asserting the supremacy of law over the king and naming many specific grievances to be resolved, the great charter attempts to standardize weights and measures. See also 1101 MATH.

1217

★ Astronomy

Michael Scot translates *Liber astronomiae* ("book of astronomy") by Abu Ishaq al-Bitruji al-Ishbili (Alpetragius) [d. 1204], introducing into Europe the Aristotelian model of astronomy. About this time he also translates works by Abu'l-Walid ibn Rushd (Averroës) and Aristotle.

1220

I Construction

The vault of the present cathedral at Chartres is completed.

See also 1194 CONS; 1240 CONS.

❖ Materials

The *Dictionary* of Jean de Garlande [b. 1190, d. 1255] mentions techniques for producing silk thread. See also 500 CE MATR; 1221 TOOL.

Σ Mathematics

The *Arithmetica* of Jordanus Nemorarius (a.k.a. Jordanus de Nemore) [most likely b. Borgentreich (Germany), c. 1190, d. at sea, 1260 (some sources say February 13, 1237)], written about this time, uses letters as variables, instead of generalizing from specific numerical cases.

Other mathematical works include *Algorismus demonstratus* ("algorithm demonstrated") and *De numeris datis* ("on given numbers"), collections of rules for solving problems. See also 1209 MATH.

Fibonacci publishes *Practica geometriae* which re-introduces Euclid's geometry and Greek trigonometry. See also 1202 MATH; 1225 MATH.

✿ Physics

Robert Grosseteste writes *De iride seu de iride et speculo* ("what the rainbow is and why"). He is the first scholar since unidentified authors of Hellenic times to recognize correctly that refraction of light is the principal cause of the rainbow and that reflection of light also contributes to its formation. Although he experiments with mirrors and lenses, his work is still highly speculative, lacking the experimental and mathematical verification of later scientists. See also 530 BCE PHY; 1304 PHY.

**Robert Grosseteste
(later Robert of Lincoln)**
[b. Stradbroke, Suffolk, England, 1168, d. Buckden, Huntingdonshire, England, October 9, 1253]

Grosseteste, the teacher of Roger Bacon, is better known as a theologian than as a scientist, but he influenced science in his time by starting a project to translate Aristotle from the original Greek (Aristotle was only available in Latin translation from Arabic at the time). His work with mirrors and lenses involved actual experimentation, leading Grosseteste to believe that light is the basic substance in the universe. Grosseteste also fought for more science teaching in universities.

Jordanus's *Elementa super demonstrationem ponderis* ("elements for the demonstration of weights") contains an early form of the principle of virtual displacements applied to the lever. He also describes in *De ratione ponderis* several simple machines, such as inclined planes and levers, and gives the first mathematical proof for the law of the inclined plane. See also 880 PHY; 1586 PHY.

→ Transportation

A window at Chartres Cathedral shows the earliest known Western wheelbarrow. See also 1 CE TRAN.

1221

I Tools

The Chinese begin to use bombs that produce shrapnel and cause considerable damage. The previous uses of gunpowder relied more on the frightening power of loud explosions. See also 1150 TRAN; 1280 MATR.

Le Livre des métiers by Jean de Garlande lists several textile machines used in the Middle Ages. *See also* 1220 MATR; 1235 TOOL.

1222

☛ Communication

The University of Padua (Italy) is founded. *See also* 1170 COMM; 1224 COMM.

▣ Construction

The Castle Tornese is built in the Peloponnesus to defend the Frankish port of Clarenza from Byzantium. *See also* 1200 CONS; 1257 CONS.

1224

☛ Communication

The University of Naples (Italy) is founded. *See also* 1222 COMM; 1229 COMM.

1225

▣ Construction

Work starts on the Cathedral of Saint Pierre in Beauvais, France, planned to be one of the largest of Gothic cathedrals, with a vault 45 m (148 ft) tall that would be the highest ever built. *See also* 1194 CONS; 1284 CONS.

Σ Mathematics

Fibonacci's *Liber quadratorum* deals with Diophantine equations of the second degree. He observes that the roots of $x^3 + 2x^2 + 10x = 20$ cannot be constructed with ruler and straightedge; in modern terms, this means that irrational numbers exist beyond those discovered by Greek geometers. *See also* 1150 MATH; 1970 MATH.

1229

☛ Communication

The University of Toulouse (France) is founded. *See also* 1224 COMM; 1231 COMM.

1230

Σ Mathematics

Hispanus Petrus (a.k.a. Pope Johannes XXI) [b. c. 1205, d. c. 1277] writes *Tractatus logicae*, subsequently known as *Summulae logicales*. It becomes the most widely used book on logic until the end of the 18th century, going through almost 200 editions. *See also* 1122 COMM; 1620 COMM.

1231

☛ Communication

Cambridge University is founded in Cambridge, England. *See also* 1229 COMM; 1244 COMM.

1232

☛ Communication

During a Mongol siege, the Chinese use kites for the first time to send messages behind enemy lines. *See also* 400 BCE TRAN.

1235

☒ Tools

A 33-page manuscript by Villard de Honnecourt contains descriptions of a variety of machines, including a hydraulic sawing machine with automatic advance of the work piece; the manuscript also contains a description of

a perpetual motion machine. *See also* 1150 TOOL.

1244

☛ Communication

The University of Rome is founded. *See also* 1231 COMM; 1253 COMM.

1245

▣ Construction

King Henry III [b. 1207, d. 1272] starts building Westminster Abbey in London, officially the Abbey of St. Peter, as an extension and replacement for an earlier structure that may go back as far as 785. The earlier structure was previously rebuilt by Edward the Confessor in the eleventh century. *See also* 1065 CONS.

♥ Medicine & health

A decree of the Holy Roman Empire permits the dissection of human cadavers. *See also* 275 BCE MED; 1319 MED.

㊐ Earth science

Giovanni de Carpini, commissioned by Pope Innocent IV, explores South Russia and reaches the Mongol Empire at Karakorum. *See also* 1253 EAR.

Σ Mathematics

Mathematical Treatise in Nine Sections by Ch'in Chiu-Shao [b. c. 1202, d. 1261] treats equations of a higher degree than the third. *See also* 1209 MATH.



CHARTRES CATHEDRAL Perhaps the most famous cathedral for architecture and for stained-glass windows, Chartres (officially Cathédrale Notre-Dame de Chartres) is considered a great spiritual center by Christians and by New Age seekers as well.

1247

☒ Chemistry

Roger Bacon is the first to mention gunpowder in Europe in a letter written this year. *See also* 1044 MATR.

Σ Mathematics

The first evidence of a Chinese sign for zero dates from this year. *See also* 876 MATH.



Roger Bacon

[b. Ilchester, England, c. 1220, d. Oxford, England, June 11, 1292]

Roger Bacon first studied and then taught in Paris before returning to England, where he carried on his studies at Oxford University. Bacon tried to summarize all the learning of the day, decrying magic but accepting astrology and alchemy. Many of his writings seem to predict in a vague way the results of modern technology. While he promoted the use of experimentation to determine truth, his writings on this subject were not published until long after experimentation had become the basis of science.

I Tools

Some type of firearm may have been used at the Siege of Seville, but the evidence for this is scanty. *See also* 1221 TOOL.

1250

★ Astronomy

Spanish monarch Alfonso X of Castile [b. Toledo, Spain, November 23, 1221, d. Seville, Spain, April 24, 1284] orders the compilation of astronomical tables, named *Alfonsoine Tables*, which will be printed in 1483. *See also* 1126 AST; 1272 AST.

Biology

On Animals by German scholar Albertus Magnus describes his observations and dissections of a number of animals and insects. *See also* 350 BCE BIO; 1551 BIO.

Chemistry

Albertus Magnus provides the first known description of arsenic, although impure forms had been used for thousands of years. *See also* 750 CHEM; 1270 CHEM.

Communication

Communication between the Mamluk Empire's twin capi-

tals of Cairo and Damascus is carried in part by carrier pigeons flying in relays and taking about one day; ordinary mail by a mounted postal service, also using relays, covers the 640 km (400 mi) distance between the capitals in only four days. *See also* 430 BCE COMM; 1461 COMM.

⊕ Earth science

In *On Animals*, Albertus Magnus calls fossils "games of nature."

II Food & agriculture

Shortly before this date, Holy Roman Emperor Frederick II writes *De arte venandi cum avibus* ("the art of hunting with birds"), summarizing his lifetime of hawking with peregrines, gyrfalcons, and saker falcons, complete with anatomy, habits, and methods of training and hunting. In it he claims to have introduced the practice of hooding hawks to

Europe, which he learned from the Arabs.

◊ Materials

Buttons with matching buttonholes come into use about this time, replacing pins and laces for closing up shirt fronts and other clothing. Buttons themselves have been known since Roman times, but they were closed with loops, not buttonholes. *See also* 500 BCE TOOL.

1253

↳ Communication

The Sorbonne University at Paris, France, is founded. *See also* 1244 COMM; 1386 COMM.

⊕ Earth science

Commissioned by Louis IX, Flemish Franciscan monk Willem van Ruysbroeck (Wilhelm von Rubruck) [b. c. 1210, d. c. 1270] explores the

road to Karakorum (Mongolia), then capital of the Mongol Empire. The capital will move to Khanbalik (Beijing, China) in 1267. *See also* 1245 EAR; 1271 COMM.

Σ Mathematics

The decimal system is introduced into England by John of Holywood (better known as Johannes de Sacrobosco) [b. Holywood, England, c. 1195, d. Paris, 1256]. *See also* 1202 MATH.

→ Transportation

According to some sources, a canal with a simple lock is built in Sparendam, Holland (the Netherlands); if so, it would be the first lock in Europe. *See also* 983 TRAN; 1373 TRAN.

1257

¶ Construction

The Teutonic Knights build the Schloss Castle of Königsberg (Kaliningrad, Russia). *See also* 1222 CONS; 1284 CONS.

1258

II Food & agriculture

Hulagu Khan conquers Mesopotamia and orders the irrigation system destroyed to aid in subjugating the population. *See also* 640 TRAN.



Albertus Magnus (born Albert, Count von Bollstädt, but known as Albert the Great)

[b. Lauingen (Germany), 1193, d. Cologne (Germany), November 15, 1280]

Albertus Magnus was a widely traveled German university professor and bishop who promoted Aristotle and alchemy, both with a touch of skepticism, however. In astronomy, he recognized that the Milky Way was composed of stars; in geology, he listed minerals and discussed fossils; and in botany, he collected and recorded data on plants from his extensive travels throughout Europe.

1259

★ Astronomy

Nasir al-Din al Tusi [b. Tus, Iran, February 18, 1201, d. near Baghdad (Iraq), June 6, 1273] starts construction of an observatory at Maragha (Maragheh, Azerbaijan), where extremely accurate observations will lead to the completion of his *Zij-i Ilkhanî* astronomical tables of planetary movements in 1272. *See also* 1200 AST.

↳ Communication

The library at Maragha is said to contain 400,000 books. *See also* 1005 COMM.

1260

↳ Communication

Bartholomew of Messina translates *Problemata* by pseudo-Aristotle from Greek into Latin. *See also* 1240 COMM.

William of Moerbeke [b. c. 1215, d. 1286] starts translation of almost the complete works of Aristotle from Greek into Latin. He also translates Hippocrates, Hero of Alexandria, Alexander of Aphrodisias, and Simplicius. *See also* 1240 COMM; 1270 MATH.

❖ Materials

The *Book of Trades* by Etienne Boileau [b. 1210, d. 1282] describes several techniques used in textile manufacture. *See also* 1280 TOOL.

Σ Mathematics

A translation of Euclid's *Elements* by Johannes Campanus (a.k.a. Campanus of Novara) [b. Novara (Italy) 1220, d. Viterbo (Italy) 1296], published about this time,

includes a method for the trisection of an angle that is probably owed to Jordanus Nemorarius; in any case, it produces only an approximation. Campanus's edition of Euclid becomes standard for the next 200 years. *See also* 1482 MATH.

♥ Medicine & health

Physician Taddeo Alderotti [b. Florence (Italy), 1223, d. Bologna (Italy), c. 1295] urges other physicians to read Galen, Hippocrates, and Avicenna, helping to bridge the gap between Greek and European medicine. *See also* 1130 MED; 1277 MED.

Contradicting accepted beliefs, Roger Bacon contends that mental illness results from natural (nondemonic) processes. *See also* 400 BCE MED; 1880 MED.

1263

■ Construction

The Cathedral of Pisa (Italy) is built to commemorate a naval victory over the Saracens at Palmero. *See also* 1240 CONS; 1318 CONS.

1267

❖ Materials

In *Opus majus*, written in 1267 and 1268 but not published until 1733, Roger Bacon becomes the first European to mention gunpowder. The book also discusses spectacles for the farsighted. *See also* 1280 MATR.

1269

❖ Physics

Pistola Petri Peregrini de

Maricourt ad Syerum de Foucaucourt, militem, de magnete ("letter on the magnet of Peter the Pilgrim of Maricourt to Sygerus of Foucaucourt, soldier") by French scholar Petrus de Maricourt (Petrus Peregrinus) [b. c. 1240, d. c. 1270–90] is the first Western account of the forces between the poles of a magnet and of a compass dial. *See also* 1190 TRAN; 1600 EAR.

1270

★ Astronomy

Chinese astronomer Guo Shoujing (a.k.a. Kuo Shou-Ching) [b. 1231, d. 1314] builds the "simplified instrument," the first known astronomical device to use an equatorial mounting. The instrument is mounted to revolve parallel to Earth's axis. When aimed at a star, it keeps it in view despite Earth's rotation. The "simplified instrument" is made from bronze and weighs several tons. It is a form of the torquetum, an improvement of the armillary sphere first described by Ptolemy. *See also* 140 CE AST; 1276 AST.

▷ Chemistry

Alchemist Arnold of Villanova [b. near Valencia (Spain), c. 1235, d. near Genoa (Italy), September 6, 1311] about this time produces the first preparation of pure alcohol and also nearly discovers carbon monoxide. *See also* 900 FOOD.

Σ Mathematics

William of Moerbeke completes his translation of almost the complete works of Archimedes from Greek into Latin. *See also* 1260 COMM; 1277 MED.

❖ Physics

Naturalist physician Witelo's *Perspectiva* ("perspectives") is a treatise on optics that deals with refraction, reflection, and geometrical optics. He rejects the notion that rays are emitted from the eye. *See also* 1020 PHY; 1604 PHY.

1271

↳ Communication

Marco Polo [b. Venice, Italy, c. 1254, d. Venice, January 9, 1324] begins his great voyage to the Far East, reaching Japan and returning in 1295. *See also* 1260 COMM; 1275 COMM.

1272

★ Astronomy

The *Alfonsine Tables*, a compilation of planetary positions that will be used extensively in the following three centuries, are completed. *See also* 1250 AST; 1483 AST.

☒ Tools

Borghesano of Bologna invents a machine for throwing silk; it remains a trade secret until 1538, when its construction becomes known in Florence (Italy). *See also* 1221 TOOL; 1607 TOOL.

1274

☒ Food & agriculture

Soon after his return from the Crusades this year, Edward I of England establishes a garden at the Palace of Westminster, including fruit trees, willows, lilies, and peonies. The influence of Islamic gardens is felt not only from Edward's experiences in the Holy Land, but also from the influence of

Moorish traditions on his first queen, Eleanor of Castile (in Spain). *See also* 1543 BIO.

1275

Communication

Marco Polo is brought to the capital of Kublai Khan by his father and uncle, Niccolo and Matteo, who had previously visited in 1266. Marco's writings become the main source of information in Europe on this period in China. *See also* 1271 COMM; 1298 COMM.

1276

Astronomy

Chinese astronomer Guo Shoujing sets up a 12-m (40-ft) gnomon for measuring the Sun's shadow. *See also* 1270 AST.

Food & agriculture

The first official whiskey distillery in Ireland begins operation. *See also* 1100 FOOD; 1527 FOOD.

Medicine & health

De formatione corporis in utero ("on the formation of the body in the uterus") by Giles of Rome [b. Rome, c. 1250, d. Avignon, France, December 22, 1316], written about this time, is a treatise on generation in the Aristotelian tradition. It discusses the contributions of both parents to procreation. *See also* 350 BCE BIO.

1277

Construction

Edward I of England [b. 1239, d. 1307] builds four fortified castles in Wales (Flint, Rhuddlan, Builth Wells, and Abergavenny).

wyh) in his campaign to subdue the Welsh. *See also* 1284 CONS.

Earth science

A great storm breaks through the sand dunes of what is now the Netherlands. The sea pours in, drowning thousands of people and enlarging the Flevo Lacus into the Zuider Zee. *See also* 12 BCE TRAN; 1556 FOOD.

Materials

A paper mill operates in Monferrato (Italy). *See also* 1391 MATR.

Medicine & health

William of Moerbeke translates various treatises by Galen from the Greek. *See also* 1260 COMM; 1559 MED.

1279

Medicine & health

Moses Farachi translates Rhazes' *Liber continens*, a medical encyclopedia, from Arabic into Latin on the orders of Charles of Anjou, king of Sicily. *See also* 900 MED.

1280

Materials

The Syrian al-Hasan ar-Rammah writes *The Book of Fighting on Horseback and with War Engines* in which he mentions the importance of saltpeter as an ingredient in compounds that produce fire and rockets, suggesting knowledge of gunpowder. *See also* 1267 MATR; 1292 MATR.

Tools

The earliest known Western reference to a spinning wheel

is made in the statutes of a guild in Speyer (in Germany). *See also* 1035 TOOL; 1480 tool

The first mechanical clocks appear in Europe soon after this date, apparently in response to stories about the existence of mechanical clocks in China. The European clocks are driven by a weight whose descent is controlled by an escapement. Chinese clocks also have escapements but still use water as the power source. *See also* 724 TOOL; 1288 TOOL.

1281

Astronomy

Nihayat al-idrak fi dirayat al-aflak by Qutb al-Din al Shirazi [b. 1236, d. 1311] contains an alternative planetary model to that of Ptolemy, making more use of uniform circular motions. *See also* 140 CE AST; 1375 AST.

1284

Construction

The roof of Beauvais Cathedral collapses, demonstrating that the trial-and-error method of Gothic construction sometimes fails. The roof of Beauvais Cathedral later collapses again. The tower, built in the 14th century, also collapses once. *See also* 1225 CONS.

Medicine & health

Mamluk Sultan Mansur Qalaun builds Mansuri Hospital in Cairo, the most sophisticated medical center of its time, with separate wards for fevers, eye diseases, surgery, dysentery, and mental illness. *See also* 1154 MED.

1285

Construction

Edward I of England builds Caernarfon Castle in Wales as part of his second campaign to subdue the Welsh. *See also* 1180 CONS; 1286 CONS.

1286

Construction

Work is completed on Harlech Castle in Wales, the second part of the Iron Ring of fortresses built by Edward I of England. *See also* 1285 CONS; 1287 CONS.

Medicine & health

Allesandro della Spina is said to make use of the invention of a friend, Salvino degli Armati; the invention is eyeglasses made with convex lenses to correct nearsightedness. Later, in 1306, Friar Giordano of Pisa claims to have known the person who invented eyeglasses 20 years earlier — although it is not clear that Friar Giordano's reference is to Armati. *See also* 1267 MATR; 1300 MED.

1287

Construction

Work is completed on Conwy Castle in Wales, part of Edward I's Iron Ring. *See also* 1285 CONS; 1295 CONS.

1288

Tools

The first known gun is made in China; small cannon, it probably has predecessors that go back ten years or more. *See also* 1247 TOOL; 1313 TOOL.

According to some authorities, a clock is installed at Westminster Abbey to mark the hours; this would have been one of the first mechanical clocks in Europe. *See also* 1280 TOOL; 1292 TOOL.

1290

★ Astronomy

William of Saint-Cloud determines the angle of the ecliptic from the Sun's position at the solstice. He finds the angle to be 23 degrees, 34 minutes ($23^{\circ} 34'$), only two minutes from today's accepted value. *See also* 450 BCE AST.

→ Transportation

By this time, South Americans are building cable bridges across deep canyons in the Andes. *See also* 415 CE MATR; 1796 CONS.

1292

◊ Materials

A Japanese woodcut made this year shows a bomb exploding, indicating that gunpowder has reached Japan. *See also* 1280 MATR; 1327 MATR.

I Tools

According to some authorities, a clock is installed at Canterbury Cathedral. *See also* 1176 TOOL; 1330 TOOL.

1295

↳ Communication

Scottish theologian and philosopher John Duns Scotus [b. Maxton or Berwick, Scotland, c. 1266, d. Cologne (Germany), November 8, 1308] starts his commentaries on Aristotle, *Quaestiones subtilis*

sime super metaphysicam Aristotelis ("subtle questions concerning Aristotelian metaphysics") about this time, which may have been finished early in the 14th century. He opposes many of the ideas of Thomas Aquinas and is thought to have influenced the thinking of such English scholars as Roger Bacon and William of Ockham. *See also* 1190 COMM.

■ Construction

The Castle of Beaumaris on the shores of Menai Straits is the last and largest of the Welsh castles of Edward I to be started. It will be completed in 1320. *See also* 1287 CONS.

1296

◊ Materials

Raymond Lully [b. Palma, Majorca, c. 1236, d. Tunis, June 29, 1315, stoned to death for preaching against Islam] discusses different technologies in his book *Arbor scientiae* ("the tree of knowledge"). He lists metallurgy, building, clothing, agriculture, trade, navigation, and the military arts and describes the theoretical knowledge required by the practitioners of these technologies. *See also* 1206 TOOL; 1423 TOOL.

1298

↳ Communication

Block printing is used in Europe for printing complete pages with woodcuts. *See also* 1105 COMM; 1460 COMM.

Marco Polo's book of his travels correctly describes such substances as coal and asbestos for the first time in Europe. *See also* 1275 COMM.

1299

Σ Mathematics

Florence (Italy) issues a decree banning the use of Arabic numerals because merchants there think that the numerals are too easy to falsify (for example, by adding a digit at the end). *See also* 967 MATH.

I Tools

A clock powered by weights of silver is built for Philip IV el Hermoso, probably by Pierre Pippelard of Paris, either this year or in 1314. *See also* 1280 TOOL; 1318 TOOL.

1300

◊ Chemistry

Alum is discovered at Rocca (Syria) about this time. Its source is kept secret for the next two centuries.

The False Geber [b. probably in Spain, c. 1270], writing under the name of the alchemist Geber of five centuries earlier, describes sulfuric acid. He is thought to have discovered nitric acid. *See also* 1317 CHEM.

■ Construction

The Mongolians build an arched dam near Kebar (Iran) curved with a radius of 35 m (115 ft) and a central angle of 40 degrees. *See also* 550 CONS; 1350 CONS.

II Food & agriculture

Methods of milling rice are developed in Lombardy (Italy). *See also* 1588 FOOD.

♥ Medicine & health

Italian physician Pietro D'Abano [b. near Padua (Italy), 1257, d. Padua, c. 1315] flour-

ishes, although his fortune from exorbitant fees and his miracle cures result in his being accused by the Inquisition of practicing magic. His *Conciliator differentiarum quae inter philosophos et medicos versantur* ("reconciler of the differences between philosophers and physicians"), known simply as *Conciliator* and not published until 1472, attempts to reconcile Greek and Arabic ideas about medicine.

Eyeglasses become common, being produced in Venice, the glass-making center of Italy, but lenses often are made from inferior glass that refracts light unevenly. *See also* 1286 MED; 1450 MED.

I Tools

Wire drawing about this time is accomplished by a worker seated on a water-powered swing. At the peak of each forward swing the worker grabs the wire with tongs. During the backward swing the wire is drawn through a small hole in a plate, thinning it, after which the worker lets go and swings forward again.

The hourglass, which measures short intervals of time by the passage of sand from one glass vessel to another, is invented. *See also* 1380 BCE TOOL.

→ Transportation

By this date carvel construction, in which boards are placed edge to edge, begins to be used in shipbuilding alongside the older clinker-planking technique in which the boards are overlapped. The carvel construction can be used to make lighter and larger ships, although clinker-planking

produces sturdier ships. *See also* 1025 TRAN; 1400 TRAN.

1303

Σ Mathematics

The first record of what is known today as Pascal's triangle is published by the great Chinese algebraist Chu Shih-Chieh (a.k.a. Zhu Shie-jie) [b. c. 1270, d. c. 1330], although it is believed that he obtained it from the Arabs, who discovered the triangle of number relationships in the eleventh century. *See also* 1527 MATH.

1304

¶ Construction

A lighthouse 49 m (161 ft) high is built in the harbor at Leghorn (Livorno, Italy). *See also* 1157 CONS; 1611 CONS.

* Physics

Theodoric of Freiburg [b. Germany, c. 1250, d. c. 1311] takes the suggestion of the master general of his Dominican order that he investigate the rainbow. This leads to Theodoric's writing *De iride* ("on the rainbow"), in which he reports on his experiments with globes of water that correctly explain many aspects of rainbow formation. *See also* 1220 PHY; 1514 PHY.

1305

⊗ Ecology & the environment

King Edward I of England bans coal burning in London when Parliament is in session. *See also* 1200 ENER; 1307 ECOL.

Σ Mathematics

The English statute acre is defined as 4840 square yards. *See also* 1101 MATH.

1307

⊗ Ecology & the environment

The practice of burning coal increases in England to the point where the lime burners of London are forbidden to use it because of the smoke, which is much more noxious than wood smoke. *See also* 1305 ECOL; 1603 ENER.

1313

↳ Communication

Wang Chen develops printing techniques and has over 60,000 Chinese characters made from hardwood at his disposal. Using these, he prints his *Treatise of Agriculture*. *See also* 1041 COMM; 1440 COMM.

I Tools

The first mention of a firearm in Western writing is of an "iron pot" or "vase," about which little else is known. The manufacturer may have been a German monk named Bernard Schwarz. Despite the name, it is thought that these early protocannon were mostly made from wooden or iron staves bound together with hoops, like a barrel. *See also* 1288 TOOL; 1347 TOOL.

1316

♥ Medicine & health

Anatomia ("anatomy") by Italian anatomist Mondino De'Luzzi [b. Bologna (Italy), 1275, d. Bologna, 1326] is the first work devoted to the

human anatomy and the art of dissection to be written in the West. It is based on the dissection of corpses. *See also* 1240 MED; 1319 MED.

1317

▷ Chemistry

Pope John XXII issues a prohibition against the practice of alchemy. *See also* 1300 CHEM.

1318

■ Construction

Scotland's largest cathedral, St. Andrew's Cathedral in St. Andrews, is consecrated; construction began in 1160. *See also* 1263 CONS; 1360 CONS.

I Tools

The clock of Cambrai, France, built by Colard LeRvre, shows the Sun, Moon, a calendar, zodiac signs, and moving figures of the apostles and angles. *See also* 1088 TOOL; 1330 TOOL.

1319

♥ Medicine & health

The first recorded case of body snatching (procurement of buried bodies for medical dissection) is prosecuted. *See also* 1316 MED.

1320

⊗ Ecology & the environment

Regulations protecting cork trees are introduced in Portugal.

♥ Medicine & health

Chirurgia ("surgery") by Henri de Mondeville (b. c. 1260, d. c. 1320) advocates

sutures and cleansing of wounds. *See also* 1316 MED; 1360 MED.

↗ Transportation

Guy de Vigevano writes a treatise on war machines for King Philip V of Valois that describes a number of devices consisting of prefabricated parts that can be quickly assembled, a new concept at the time. One of the devices described is a ship powered by propellers turned by cranks. *See also* 1775 TRAN.

1321

Σ Mathematics

Levi ben Gerson [b. Bagnols, France, 1288, d. 1344] uses mathematical induction to establish formulas for the number of permutations of n objects and combinations of n objects taken r at a time. *See also* 1575 MATH.

1323

↗ Energy

A manuscript from Briey in France describes bellows driven by a water wheel. It is the first such description known in the West. *See also* 1086 ENER.

1325

▲ Archaeology

About this time the Aztecs found Tenochtitlán, where they see an eagle sitting on a cactus with a snake in its beak, an omen they had been seeking. Later the Spanish rebuild the city as Mexico, the present capital of the nation of Mexico. *See also* 700 CONS.

1326

Earth science

Ibn Battuta of Tangier begins his exploration of India, Ceylon, and the Far East, returning in 1350. He becomes the most traveled person of his time. *See also* 1275 COMM; 1352 EAR.

Tools

A drawing of small cannon that fires arrows, which appears in Walter de Milemete's *De officiis regum* ("on the duties of kings"), is the first illustration of a gun in Europe. *See also* 1313 TOOL; 1347 TOOL.

1327

Materials

A treatise with this date is sometimes identified as the first mention of gunpowder in the West, although Roger Bacon had written of it earlier and there is some written evidence of firearms before this. *See also* 1292 MATR; 1625 MATR.

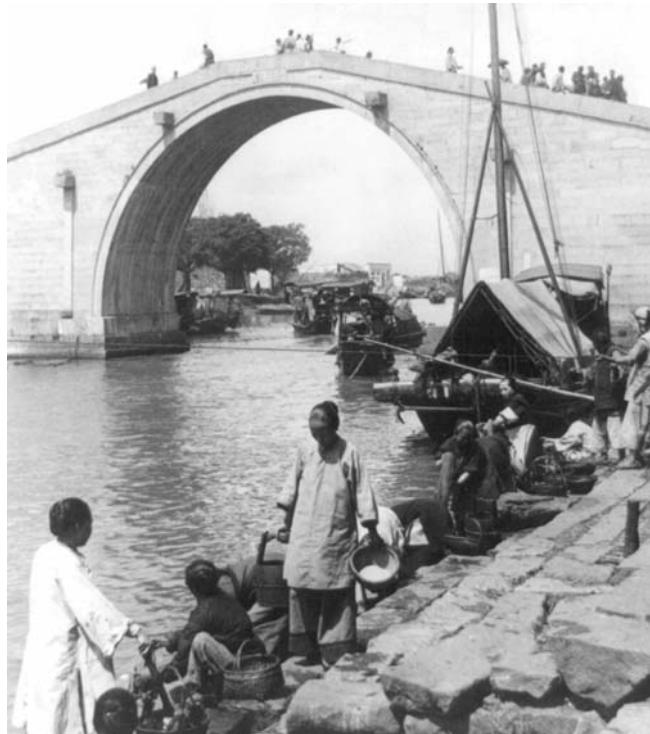
Transportation

China's Grand Canal, 1770 km (1100 mi) long, is completed. Built over many centuries, starting in 70 CE, it connects Beijing to many parts of northern China and to the Yangtze. A major link between the Yangtze and the Huang He (Yellow River) was built by the emperor Yangdi between 605 and 610. *See also* 610 TRAN.

1328

Physics

Thomas Brandwardine's *Tractatus de proportionibus* develops a theory of proportions that he uses to improve upon



GRAND CANAL OF CHINA The longest as well as the oldest waterway built by humans that is still in use, the Grand Canal, with 24 locks and 60 bridges, forms the main water connection between north and south China. It has long been instrumental in maintaining China as a single nation.

Aristotle's laws of motion (although Brandwardine's laws are also incorrect). *See also* 350 BCE PHY; 1350 PHY.

1330

Communication

Summa totius logicae by philosopher and theologian William of Ockham, or Occam, introduces the notion that when several explanations of a phenomenon are offered, the simplest must be taken. Often expressed as "entities must not be needlessly multiplied," this concept, called Ockham's razor, has become one of the foundations of science.

William of Ockham (Occam)

[b. Ockham, Surrey, England, c. 1284, d. Munich (Germany), 1349]

William was among the last of the scholars of the Middle Ages, and like most, a churchman (required for teaching at Oxford in his time), but in more trouble with the church for his heretical views than most earlier scholars. Ockham's principal fame resulted from his battle against the Platonic philosophy of nominalism, for which his famous "razor," or rule against complicated explanations, was intended. Its prime use, however, has been in choosing between competing scientific theories.

Tools

According to a contemporary manuscript, Richard of Wallingford [b. Wallingford, England, c. 1292, d. St. Albans, Hertfordshire, England, May 23, 1336] makes an elaborate clock for St. Alban's Abbey in England in this year or in 1326. It shows many astronomical configurations and is among the early weight-driven mechanical clocks for which evidence still exists. *See also* 1318 TOOL; 1335 TOOL.

1335

Tools

A mechanical clock built by Guglielmo Zelandino is mounted in a tower of the San Gottardo Chapel in Milan (Italy); it is the first public clock that strikes the hour. *See also* 1330 TOOL; 1354 TOOL.

The compound crank handle is invented. *See also* 830 TOOL; 1430 TOOL.

1336

Mathematics

The University of Paris decrees that no student can graduate without attending lectures on "some mathematical books." *See also* 1210 COMM; 1452 MATH.

1337

Earth science

William Merlee of Oxford University, England, tries to forecast the weather. *See also* 330 BCE EAR; 1869 EAR.

1339

Food & agriculture

Zen priest Muso-Soseki introduces the use of smooth, flat-topped stones in his garden in Kyoto, Japan. *See also* 1274 FOOD.

1340

Materials

The first blast furnace is developed in or around Liège (Belgium). *See also* 1200 MATR; 1856 MATR.

Transportation

A German miniature representing the Flight from Egypt shows a cart with a suspension for absorbing shocks. Such suspensions are believed to have been introduced about this time. *See also* 100 BCE TRAN; 1457 TRAN.

1344

Construction

Jocopo di Dondi builds a clock tower in Padua. *See also* 1335 TOOL; 1348 TOOL.

1345

Construction

Taddeo Gaddi [b. Florence (Italy), c. 1300, d. Florence, 1366] designs and builds the bridge we now call the Ponte Vecchio (old bridge) in Florence. The Ponte Vecchio is a segmental arch bridge, an improvement over the pure semicircular arches that were used in most previous bridges. *See also* 610 CONS; 1355 CONS.

Medicine & health

Plague spread by fleas on rats, endemic in parts of central Asia, breaks out as trade

between Asia and Europe increases and spreads to Astrakhan (in Russia) on the Volga and Caffa (Feodosiya, Ukraine) in the Crimea; it is the beginning of the epidemic known as the Black Death. *See also* 431 BCE MED; 1347 MED.

1346

Materials

On August 26 an English army under Edward II defeats a much larger French army at Crècy, France, partly because the high kinetic energy of their flax-strung longbows can penetrate French armor made from iron with a high carbon content. *See also* 490 BCE MATR; 1415 MATR.

1347

Medicine & health

Italian ships bring rats carry-

ing fleas infected with the Black Death to Europe. Plague spreads to Mediterranean ports and begins to terrorize people all over Europe as they hear of its terrible symptoms and many deaths. The epidemic kills 25,000,000 people, a third of the population, before 1351. During the next 80 years it will recur over and over, at least once in each 8 years, and will kill three-fourths of the population of Europe. *See also* 1345 MED; 1348 MED.

Tools

English soldiers use ten cannon at the siege of Calais. Although there is some evidence of earlier use of cannon, it is not so clear-cut as that for this battle. *See also* 1326 TOOL; 1350 TOOL.



PONTE VECCHIO A wooden bridge crossed the Arno in Florence at this spot as early as 972 CE, but was lost to a flood in 1333. The stone Ponte Vecchio that replaced it, now well over 600 years old, has always been lined with shops — originally butcher's shops, but since the 16th century mostly gold, silver, or jewelry shops. A trio of archways midstream allows strollers to look out over the river.

1348

♥ Medicine & health

Black Death is imported to England from France by ships carrying claret wine and flea-infested rats. *See also* 1347 MED; 1352 MED.

I Tools

Giovanni di Dondi [b. Chioggia (Italy) c. 1330, d. Genoa (Italy), 1389], probably working with his father Jocopo di Dondi, starts building a famous astronomical clock, completing it in 1364. *See also* 1330 TOOL; 1364 TOOL.

1350

■ Construction

Mongolian engineers build an arched dam 60 m (200 ft) high near Kurit (Iran). *See also* 1300 CONS; 1850 CONS.

✿ Physics

Philosopher Jean Buridan [b.

Béthune, France, c. 1295, d. Paris, c. 1358] develops the idea of impetus, a concept close to the notion of inertia, and rejects the idea that God or angels propel the celestial bodies on their orbits continuously. He asserts that an initial impetus is sufficient to explain their motion. *See also* 1328 PHY; 1613 AST.

I Tools

About this time, or at least sometime before 1364, the first bronze cannons are introduced. They are still not cast as a single piece, but are fashioned by joining several parts. *See also* 1347 TOOL; 1378 TOOL.

1352

■ Construction

In Segovia, Castile (Spain), the Alcazar is built (*Alcazar* is Moorish for “the castle”). Perhaps because of the invention of cannon, it is the last of the

great fortified castles. *See also* 1295 CONS.

⊕ Earth science

Ibn Battuta explores the Sahara. *See also* 1326 EAR.

♥ Medicine & health

The Black Death reaches northern Europe, including Scandinavia and northern Russia. *See also* 1348 MED; 1377 MED.

1354

I Tools

The mechanical clock in Strasbourg Cathedral is built. On top of the tower is a mechanical cock that flaps its wings and crows at twelve o’clock (the cock still exists in the Strasbourg Museum). Around this time clocks are also installed in Padua, Genoa, Bologna, and Ferrara. *See also* 1330 TOOL; 1386 TOOL.

1355

■ Construction

The segmental-arch bridge Ponte Castelvecchio is built over the river Adige at Verona, Italy, with a major span of 49 m (160 ft). *See also* 1345 CONS; 1569 CONS.

◊ Materials

The University of Paris, much interested in an alternative to parchment, licenses the construction of paper mills in Troyes and Essonnes. *See also* 1277 MATR; 1391 MATR.

1360

⌚ Communication

Nikolaus Faber builds for the Halberstadt cathedral the first pipe organ to have a complete scale including semitones. It uses three keyboards as well as foot pedals. *See also* 120 CE COMM; 1400 COMM.

Impetus and inertia

In Antiquity Greek scholars wondered what keeps the stars, which they believed are attached to a giant crystal sphere, in motion. Aristotle did not believe that motion without an agent of motion is possible and suggested that some agent keeps rotating the sphere that contains the fixed stars.

Many of Aristotle’s ideas about motion were generally accepted until the 17th century. However, in the sixth century CE, philosopher Johannas Philoponus had already rejected Aristotle’s idea that a body would move only as long it is pushed. Philoponus believed that motion is a quality, like the Aristotelian qualities of warmth or moisture. Once a body is set in motion, it will keep moving in the absence of friction because a moving body contains a certain quantity of the quality of motion. The sphere of the stars can move because nothing opposes it.

In the 13th century, Thomas Aquinas believed that it is God that keeps our sphere in rotation; the fact that the stars move

was for him proof of the existence of God. This view was made official in the condemnation of 1277, a papal decree intended to suppress speculation that might contradict the teachings of the church.

Nevertheless, the ideas of Philoponus were adopted by some in the 14th century. William of Ockham and Jean Buridan called the quality of motion *impetus*. These scholars avoided the problem of the condemnation of 1277 by invoking God as the originator of impetus and by saying that God could change motions if He pleased.

In the 17th century, Galileo added experimentation to medieval speculation and showed that something like the impetus idea must be true. Galileo came very close to the modern idea of inertia. Finally, Newton replaced impetus with inertia. The main difference between impetus and inertia is that inertia applies both to bodies at rest and bodies in motion. Before Newton, none of the philosophers had thought that the same concept could describe stationary and moving bodies.

Early mechanical clocks

In Antiquity people told time by the Sun and stars. A boy and girl might arrange to meet during the evening when Venus falls below the horizon. In the event of clouds, they could guess at the meeting time. Serious consequences if they guessed wrong seldom occurred.

Other methods of keeping time could be used as backups, however. Water clocks (clepsydras) had been known since ancient Egyptian times. These depended on the relatively constant lowering of the level of water in a vessel with a deliberately made leak. Clepsydras were not very accurate, not easy to read in a poor light, and needed frequent refilling to be of any use. Burning tapers and lamps might also show the passage of time, but time varied with the specific taper or lamp.

In the Middle Ages, however, members of religious orders were expected to pray at definite times. Failure to maintain godly habits because of cloudiness or variable flames was not acceptable. There was an answer, however. Sources from Antiquity (and probably rumors of Chinese inventions) referred to devices that could imitate the Sun and stars. Such devices were powered by water clocks, but the Chinese rumors may have told of a clever device, which we call an escapement, that could convert the smooth motion of water flowing into a series of short rotary motions. These motions could give a more accurate representation of the movement of astronomical bodies.

In duplicating this concept, an unknown European inventor recognized that with an escapement to slow the fall, a weight could be substituted for water. If the weight were lifted by hand at regular intervals, there would be no need to deal with the continual addition of water to operate the mechanism. The falling-weight idea, however, required something to make it more regular, since a weight accelerates, or falls faster, as it goes

along. If the weight could be made to fall the same short distance over and over, the motion would be more regular. This was accomplished by adding a sort of dumbbell, called a *foliot*, to the escapement. The weights at the end of the foliot fall a short distance with each tick of the clock, each one balanced by the other one. The combined fall of the weight that powers the clock and the short stroke of the foliot gave the time off by only an hour or so each day. The earliest mechanisms of this type, around the end of the 13th and beginning of the 14th century, were used to power representations of the heavens. Thus, if the clock was out of whack when the weight was pulled up, it could be reset on any clear day or night by comparing the representation with the actual positions of heavenly bodies.

The monks and nuns were summoned to prayer by a bell. Soon someone realized that the elaborate astronomical model was not needed; a system of striking the hour with a series of rings of the bell was sufficient. Sometime after that, people added a dial to show the hours with a pointer (hand). A similar pointer for minutes was not needed until clocks greatly improved in accuracy. Although the first clocks were installed for use in religion, within a few years people began to keep time by the hours, since the ringing of the bell often could be heard or the dial seen all over a village.

The manufacture of clocks became a thriving industry in the 14th and 15th centuries. Every town soon had to have its own. Although the basic mechanism did not change during this period, the development of better ways to cut gears and to make other metal parts was an important precursor of the Industrial Revolution. No other artifact of this period required such careful workmanship.

Despite this, clocks were not nearly accurate enough to bother with minutes, much less seconds. When Galileo needed to time short intervals around the turn of the 17th century, he used his pulse because clocks were not sufficiently accurate.

Construction

Gloucester Cathedral, built about this time, initiates the period of the Perpendicular style of Gothic architecture in England, which becomes very popular and persists until the English Renaissance of the 16th and 17th centuries. See also 1318 CONS.

Mathematics

Tractatus de figuratione potentiarum et ensurarum by Nicole Oresme (a.k.a. D'Oresme) [b. Auvergne, France, c. 1300, d. Avignon, France, July 25, 1368] describes how to treat frac-

written about this time, describes his "latitude of forms," a precursor of analytic geometry, calculus, and even the fourth dimension. Oresme also introduces rational and irrational powers in *De proportionibus proportionum*, composed about this time. See also 1629 MATH.

Medicine & health

Chirurgia magna by surgeon Guy de Chauliac [b. Auvergne, France, c. 1300, d. Avignon, France, July 25, 1368] describes how to treat frac-

tures and hernias. See also 1320 MED; 1460 MED.

1364

Tools

Giovanni di Dondi publishes the first description of a modern clock, weight-powered, escapement-regulated, and with a balance wheel. This form of clock is evidently invented about this time by Dondi or members of his family, although key elements, such as the escapement, are no doubt borrowed from the

Chinese or other Western clockmakers. Dondi's famous astronomical clock, using these principles, is built between 1348 and this time. See also 1348 TOOL; 1406 TOOL.

1370

Ecology & the environment

Paris requires butchers to dispose of animal wastes outside the city. See also 1388 ECOL.

Food & agriculture

Inventories of the possessions of Charles V of France reveal that he had gold and silver forks, although the forks were only used for eating mulberries and foods likely to stain the fingers. *See also* 1100 FOOD; 1533 FOOD.

Tools

The steel crossbow powered with a crank or with a windlass and pulley, called an arbalest, is introduced as a weapon of war. *See also* 1346 MATR.

1373

Transportation

The first record of a canal lock in the West, many believe, describes a lock at Vreeswijk in Holland (the Netherlands) built this year, although others think the first Western locks were constructed a few years later in Italy or over 100 years earlier at Sparendam, Holland. Canal locks had been known in China for almost 400 years. *See also* 1253 TRAN; 1395 TRAN.

1375

Astronomy

Kitab Nihayat al-Sul fi Tashih al-Usul (“a final inquiry concerning the rectification of planetary theory”) by Ala al-Din Abul-Hasan ibn Al-Shatir [b. Syria, c. 1305, d. 1375] includes a non-Ptolemaic theory of planetary motions claimed to have the first correct account of the path of planet Mercury in terms of uniform circular motion. Shatir also devises a description of the path of the Moon based on the

model developed by Nasir al-Din al-Tusi that does not involve epicycles, yet still brings the Moon much closer to Earth and then much farther away. *See also* 1281 AST; 1472 AST.

Materials

About this time German potters achieve production of true stoneware and a salt glaze, the first such pottery in Europe. *See also* 1150 MATR; 1616 MATR.

1377

Medicine & health

The first quarantine station is set up in the port of Ragusa (Dubrovnik); those suspected of plague have to stay there for 40 days. *Quarantina* in Italian means 40, so this period of waiting comes to be known as a quarantine. *See also* 1352 MED.

1378

Tools

The first cast-bronze cannon made in a single piece in the West is cast at Augsburg (Germany). *See also* 1350 TOOL; 1542 TOOL.

1379

Communication

Gabriel de Lavinde, secretary to Pope Clement VII, writes a manual on cryptography. *See also* 1623 COMM.

1380

Materials

Cast iron becomes generally available in Europe. *See also* 1340 MATR.

Transportation

Rockets are used for the first time in Europe in the battle of Chioggia (Italy) between the Genoese and the Venetians. *See also* 1150 TRAN; 1650 TRAN.

1381

Tools

The first small arms made in the West, known as fire sticks, are mentioned in writing. *See also* 1425 TOOL.

1386

Communication

Heidelberg University is founded, the oldest continuously existing university in Germany. *See also* 1253 COMM; 1409 COMM.

Construction

Construction of the cathedral in Milan begins. Its design with four towers at the corners of the central tower is intended to represent Christ surrounded by the four evangelists. After a few years of construction, however, it becomes apparent that there are structural flaws and French and German advisers are called in. They recommend more geometry and less “art.” *See also* 1263 CONS; 1387 TRAN.

Tools

The earliest built mechanical clock that survives today is a device in Salisbury Cathedral in England built at this time. The clock does not tell time with hands, but sounds the hour and indicates astronomical events. *See also* 1280 TOOL; 1406 TOOL.

1387

Transportation

Work continues on the Milan cathedral and the Bishop of Milan has branch canals built from the moat supplied by the Naviglio Grande. He uses the branch canals, which are lower than the moat by a meter or so, to ferry stone to the site of the cathedral under construction. A stanch (gate) is used to allow boats to pass from the main canal into the branches and back. *See also* 1209 TRAN; 1438 TRAN.

1388

Ecology & the environment

In England, Parliament bans disposal of garbage into rivers and ditches. *See also* 1370 ECOL; 1400 ECOL.

1390

Communication

Metal type is used for printing in Korea. *See also* 1313 COMM; 1440 COMM.

1391

Materials

A paper mill is established in Nuremberg (Germany). *See also* 1355 MATR; 1494 MATR.

Tools

A Treatise on the Astrolabe by Geoffrey Chaucer [b. c. 1342/43, d. London, October 25, 1400] shows how to construct such a device and how to use an astrolabe to compute the elevation of a star. *See also* 1490 TOOL.

✈ Transportation

A 24-km (15-mi) canal is constructed from Lake Mölln to the river Delvenau (Germany). The canal enables traffic to pass from the Baltic up the river Stecknitz, through Lake Mölln, along the canal, down the river Delvenau to the river Elbe and on to the North Sea. Along the way a boat would go over a dozen stanches on the rivers and pass through two locks on the canal. *See also* 1387 TRAN; 1395 TRAN.

1395

✈ Transportation

Locks are installed on the Po River, making it possible for barges to transport marble for the construction of a cathedral being built in Milan. *See also* 1387 TRAN.

1396

✈ Transportation

The first representation of a four-wheeled cart with a turning front axle is found on a seal of François of Carrara. *See also* 1340 TRAN; 1457 TRAN.

1399

🏗 Construction

English King Richard II makes Westminster Hall more impressive by having an unsupported roof built to cover the hall. Carpenter Hugh Herland and architect Henry Yevele design a ceiling, supported by great beams shaped like hammers, that still stands. *See also* 1097 CONS.

1400

★ Astronomy

By this date the Chinese have learned that the length of the solar year is about 365.25 days. *See also* 1200 AST.

⌚ Communication

The dulcimer is mentioned for the first time. *See also* 1360 COMM.

❀ Ecology & the environment

Hughes Aubriot, provost of Paris and builder of the Bastille, roofs over a stretch of the open ditches that serve as sewers in Paris (as such ditches do in most medieval cities). Eventually, all the drainage ditches of Paris are covered, giving some semblance of a sewer system. *See also* 1388 ECOL.

❖ Materials

Oil begins use as a base for paints. *See also* 1420 COMM.

I Tools

During this century the suction pump is invented. *See also* 1650 TOOL.

✈ Transportation

A lateen sail rigged fore and aft and carried on a mizzenmast begins to be used in the Basque region of Spain around the Bay of Biscay. Its use spreads rapidly to northern Europe and the Mediterranean. *See also* 1570 TRAN.

The Chinese ship called the junk has four permanent masts and two temporary ones, lugsails stiffened with battens of bamboo, a central rudder, and a hold divided into watertight compartments. Fleets of junks patrol

the Indian Ocean to as far away as Ceylon, some with crews of 600 or more. *See also* 1414 TRAN.

By this date carvel-constructed ships weighing up to 1000 tons are in existence in Europe, far larger than any European ships in Antiquity, although perhaps matched in size by Chinese junks. *See also* 1300 TRAN; 1450 TRAN.

1403

⌚ Communication

Yung lo ta tien (a.k.a. *Yongluo dadien*, or “vast documents of the Yung-lo Era”), a Chinese encyclopedia in 22,877 manuscript rolls, is produced. Later it will be transcribed into two other copies, but by 1644 much of the text will have been lost — about 3 percent of the original remains. *See also* 1694 COMM.

1405

I Tools

Konrad Kyeser's *Bellifortis* discusses military technology, including fortifications and war machinery. *See also* 1455 COMM.

1406

⌚ Communication

Jacopo d' Angelo di Scarperia translates the *Geography* of Ptolemy (Claudius Ptolemaeus) into Latin, allowing it to greatly influence the European view of the world. *See also* 140 CE EAR; 1544 COMM.

I Tools

An illuminated manuscript from France from this time shows one of the earliest

known mechanical, weight-driven clocks to use a balance wheel instead of a weighted bar (foliot) as part of the escapement. *See also* 1364 TOOL.

1409

⌚ Communication

Leipzig University is founded by German refugees from Prague. *See also* 1386 COMM; 1426 COMM.

In Scotland, St. Andrews University in Edinburgh is founded. *See also* 1231 COMM; 1426 COMM.

1410

★ Astronomy

Hasdai ben Abraham Crescas's *Or Adonai* (“the light of the Lord”) contains a refutation of Aristotle's argument of the absence of other worlds. *See also* 350 BCE AST.

馌 Food & agriculture

Dutch fishers become the first to use drift nets. *See also* 1190 FOOD.

♥ Medicine & health

Benedetto Rinio's *Liber de simplicibus* (“book on medicinal herbs”) describes and illustrates 440 plants that have medicinal uses. *See also* 40 CE MED; 1493 MED.

1414

⚡ Energy

A windmill is used in Holland to carry water from inland areas out to sea. *See also* 1185 ENER; 1450 ENER.

♥ Medicine & health

Influenza is recorded for the first time in Paris.

→ Transportation

At the command of Emperor Yong'le a giant exploring expedition sets out from China under the leadership of the grand eunuch Admiral Zheng He. The fleet, consisting of 62 giant junks, the largest more than 120 m (400 ft) long and 45 m (150 ft) wide, carrying about 150 tons, brings about 30,000 Chinese to what are now known as India, Sri Lanka, and Saudi Arabia, as well as perhaps traveling the length of the African east coast from Somalia to what is now the Republic of South Africa. The fleet returns safely with trade goods and gifts from the Africans in 1415. Further exploration continues for about 20 years. *See also* 1400 TRAN; 1433 EAR.

1415

⊕ Earth science

European expansion starts with the Portuguese capture of Ceuta (across from Gibraltar), so that Prince Henry the Navigator [b. Oporto, Portugal, March 4, 1394, d. Sagres, November 13, 1460] can use it as a base for further African operations. *See also* 1418 EAR.

■ Construction

Papal secretary Poggio rediscovers the lost manuscript of *De architectura* by Vitruvius, believed to have been written about 25 BCE. *See also* 25 BCE ENER; 1486 CONS.

◊ Materials

On October 25 English longbow forces under Henry V

defeat French armies at Agincourt. The French are heavily armored. At Crècy in 1346 the English arrows, propelled from stiff bows with flaxen strings, had penetrated French iron armor. At Agincourt, mud is a factor as the heavily armored French sink in it readily and are unable to rise after falling. The lightly armored English archers dispatch the French despite — or because of — the heavy armor. *See also* 1346 MATR.

1417

⌚ Communication

A copy of Lucretius's *De rerum natura* ("on the nature of things") is found in manuscript in a monastery; it is the first version available since Roman times. Scholars since have found another partially legible copy in the ruins of Herculaneum. *See also* 50 BCE BIO; 1473 PHY.

1418

⊕ Earth science

Portuguese sailors rediscover (and claim) Madeira, which had been discovered about 70 years earlier by sailors from Genoa, but forgotten. *See also* 1415 EAR; 1420 EAR.

1419

■ Construction

Filippo Brunelleschi [b. Florence (Italy), 1377, d. 1446] starts construction of his design for a dome over the roofless cathedral of Santa Maria del Fiore in Florence (Italy). The dome, completed in 1436 and bridging a gap of 42 m (138 ft), still stands and is known to one and all simply

as il Duomo. The dome itself is somewhat wider than the gap at 43.5 m (143 ft) and 32 m (105 ft) tall, but its total height with the cathedral under it, but not including a 600-ton stone lantern, is about that of a 35-story building: 107 m (351 ft). *See also* 532 CONS.

⊕ Earth science

Niccolo Conti of Venice explores India and reaches China via Burma. *See also* 1352 EAR; 1466 EAR.

1420

⌚ Communication

The painters Hubert van Eyck [b. c. 1370, d. 1426] and Jan van Eyck [b. Flanders, c. 1390, d. Bruges (Belgium), July 9, 1441] are the first to use oil paints systematically. Before them painters normally used paint based on albumen (egg whites), although oil paints had been used on a few earlier occasions. *See also* 1400 MATR.

⊕ Earth science

Portugal's Prince Henry, known as "the Navigator," sets up an informal clearing-house of naval knowledge and center for exploration at Sagres, on the southwestern tip of Portugal. From this port city Portuguese ships set forth to explore the Atlantic and the African coastline. *See also* 1418 EAR; 1432 EAR.

▣ Tools

The bit and brace system for drilling holes is invented. *See also* 100 CE TOOL.

The *Book of Fireworks*, a handbook for gunners, is published in Germany; it will continue

to be printed until the 16th century. *See also* 1537 PHY.

1421

→ Transportation

Filippo Brunelleschi receives the first known patent from the Republic of Florence (Italy); it is for a canal boat equipped with cranes. *See also* 1474 COMM.

1423

I Tools

Conrad Mendel publishes between 1423 and 1429 a book describing late medieval crafts and depicting 355 craftsmen; the work is known as the *Mendel Book*. *See also* 1296 MATR; 1499 TOOL.

1424

★ Astronomy

Mongol astronomer Ulugh Beg builds an observatory at Samarkand that contains the world's largest astrolabe, having a radius of 40 m (132 ft), giving it a precision of from two to four arc seconds. *See also* 829 AST; 1540 TOOL.

1425

I Tools

About this time, or at least sometime before 1475, the first genuine flintlock small arms (similar to muskets) are introduced. *See also* 1381 TOOL.

1426

⌚ Communication

Louvain University (Belgium) is founded. *See also* 1409 COMM.



IL DUOMO Although several Italian cities have large domed churches that they locally call il duomo, the dome of the cathedral of Santa Maria del Fiore in Florence, which dominates that city, is the duomo that all the world knows.

1430

★ Astronomy

Ulugh Beg publishes new tables of star positions and a new star map. These are improvements on those of Ptolemy and Hipparchus. *See also* 1424 AST.

I Tools

The earliest representation of a drive belt in Europe shows it being used to turn a grind-stone. *See also* 1335 TOOL.

Ulugh Beg ("Great Ruler"), or Muhammad Taragay

[b. Soltaniyeh (Iran), March 22, 1394, d. Samarkand (Uzbekistan), October 27, 1449, assassinated by his son]

Ulugh Beg, as Muhammad Taragay is almost universally called, was the grandson of Tamerlane, who conquered much of central Asia. His devotion to science began before he succeeded to his grandfather's throne in 1447, as he founded a university in Samarkand and built his world-class observatory there more than 20 years earlier. His observations were superior to any in Antiquity, but were unknown in Europe until the 17th century, although published in Arabic and Persian much earlier.

1432

⊕ Earth science

Noting the Azores marked on an Italian map of 1351, Portuguese Prince Henry the Navigator assigns explorer

Gonzalo Cabral to find the now lost islands, which he does. Over the next dozen years Portuguese begin their colonization of the islands. *See also* 1420 EAR; 1440 EAR.

1433

★ Astronomy

Physician, astronomer, mathematician, and mapmaker Paolo dal Pozzo Toscanelli [b. Florence, Italy, 1397, d. Flo-

rence, May 10, 1482] reports on a comet, measuring its movements precisely. *See also* 1066 AST; 1450 AST.

Earth science

Financial difficulties in Ming dynasty China result in the stoppage of all further exploration of Africa after several voyages over a 20-year period. *See also* 1414 TRAN.

1436

Communication

Leon Battista Alberti [b. Genoa (Italy), February 18, 1404, d. Rome, April 25, 1472] writes *De pictura* (“on painting”), which explains how to calculate the correct proportions of figures viewed at different distances and how to make the planes of a painting converge on a point. These ideas on perspective become the main focus of Renaissance



Nicholas of Cusa (Nicholas Krebs)

[b. Kues (Germany), 1401, d. Lodi (Italy), August 11, 1464]

Nicholas of Cusa studied at both Heidelberg and Padua, where he earned a law degree in 1423, but in 1430 he entered the church, becoming a cardinal in 1448. His ideas about the universe were generally ahead of their time, including modern views on astronomy, botany, and medicine — but they were seldom backed with experiment or other proof. His invention of concave lenses for nearsightedness was an important advance.

painting and eventually will lead to a new branch of mathematics, projective geometry. *See also* 1420 COMM; 1470 COMM.

Transportation

Shipyards in Venice introduce interchangeable parts for ships and build galleys on an assembly line. A visitor from Spain observes the assembly line in operation and notes that ten galleys are produced in six hours. *See also* 1400 TRAN.

1438

Transportation

Filippo da Modena and Fioravante da Bologna install a canal lock (and later a second one) on the Naviglio Grande, replacing the stanch where branch canals to the cathedral connect to the moat around Milan. This is among the earliest known locks in the West. *See also* 1387 TRAN; 1458 TRAN.

1440

Astronomy

De docta ignorantia (“on learned ignorance”) by Nicholas of Cusa contains the idea of an infinite universe and proposes that all heavenly bodies are essentially alike and that Earth revolves about the Sun. He declares that stars are simply faraway suns but does not offer much in the way of observational proof. His ideas are not generally accepted. *See also* 1543 AST.

Movable type

Most people have the general idea that Gutenberg invented printing. A few who think they know better believe that although the Chinese developed printing, Gutenberg invented movable type. Neither is actually true — Chinese inventors created printing, the paper to print on, and movable type made from wood or ceramics. These concepts spread to the West relatively soon after their invention, especially the manufacture of paper.

Gutenberg's actual inventions were two. Although he was not the first to try casting metal type — the Chinese had tried it and found it too difficult to do properly — he created the first system for casting type so that the letters could form a flat surface, essential to their use in printing. And he invented a printers' ink that would function with metal type. The arrangement he developed to use a modified wine press to impress type held in wooden forms on paper was good enough not to change in any substantial way for about 300 years. From the very first, Gutenberg

produced what we still recognize as printing of the highest order.

Little is known about Gutenberg the person. Johann Gutenberg was a goldsmith from Mainz, Hesse (Germany), born just at the end of the 14th century. He was on the losing side of a political conflict in Mainz when he was in his early thirties and, as a result, moved to Strasbourg, then a free city. There is a tiny bit of evidence that by 1435 he had turned from goldsmithing to work at least part time on the development of printing. As a goldsmith, Gutenberg was already accustomed to making stamps used to mark his products. The stamps commonly used by goldsmiths and silversmiths, small punches that leave the mark impressed into the soft gold or silver, are each very close to a single piece of type.

When Gutenberg printed a popular encyclopedia in 1460, the *Catholicon*, he described the achievement as “printed and accomplished without the help of reed, stylus, or pen but by the wondrous agreement, proportion, and harmony of punches and types.”

Communication

Johann Gensfleisch zum Gutenberg [b. Mainz (Germany) c. 1398, d. Mainz, February 3, 1468] and Lauren Janszoon Koster invent printing with movable type about this date, probably independently of the Chinese. However, the inventions of paper and printing with blocks, essential to printing with movable type, had both most likely been learned as a result of diffusion to Europe from China. The date of 1440 that is often given for Gutenberg's invention is inferred in part because by 1450 he was borrowing money to build equipment and to start printing broadsides, pamphlets. *Speculum nostrae salutis* ("mirror of our salvation"), printed by Koster, is probably the earliest printed book. *See also* 1041 COMM; 1454 COMM.

Earth science

The European slave trade in Africa begins when one of the Portuguese explorers sent out by Prince Henry the Navigator returns with a dozen Africans. (African slave trading by Arabs was already hundreds of years old.) Within the decade hundreds of Africans are sold at public auction in Portugal. *See also* 1418 EAR.

1447

Food & agriculture

Willem Beukelsz introduces a method for curing herring in brine aboard ships; the herring is thus preserved and can be sold directly upon arrival ashore. *See also* 1000 BCE FOOD.

1450

Astronomy

Paolo Toscanelli measures the path of a comet seen in 1449 and this year. *See also* 1433 AST; 1456 AST.

Biology

Nicholas of Cusa publishes a work in which he advocates the use of the balance in the study of plant growth. *See also* 1648 BIO.

Communication

Greek scholar John Bessarion [b. Trebizond (Turkey) January 2, 1403, d. Ravenna (Italy), November 18, 1472] regularly entertains Italian and Greek scientists in his home, forming the first *Accademia*, devoted to Platonic philosophy. *See also* 529 CE MATH; 1603 COMM.

Energy

The Dutch invent the *wipmolen*, a form of windmill in which the top portion, bearing the sails, can be turned to face the wind. *See also* 1502 ENER.

Medicine & health

Gold is used for filling teeth. *See also* 1828 MED.

Physics

Nicholas of Cusa proposes the timing of falling bodies. *See also* 1586 PHY.

Tools

Nicholas of Cusa constructs spectacles for the nearsighted. *See also* 1286 MED.

Transportation

Portuguese shipbuilders develop the ship called the caravel, the basic type of ship



DUTCH WINDMILL The best known of many types of windmill is still the variety invented in Holland with giant sails for a rotor and a rotating turret so that the sails can face the wind. With the aid of these mills, the Dutch drained large regions that otherwise would be under water and turned them into productive farmland.

1452

Materials

Henry VI of England accepts immigration of Hungarian and Bohemian miners for the improvement of mining practices in England. *See also* 1505 MATR.

Mathematics

The University of Paris begins to require that students must have read the first six books of Euclid to get a master's degree. *See also* 1336 MATH.

Medicine & health

The first professional association for midwives is founded in Regensburg, Germany. *See also* 1500 MED.

1451

Materials

Johanson Funcken develops a method for separating silver from lead and copper. Ores of the three metals are often mixed in deposits.



The Renaissance and the Scientific Revolution: 1453 through 1659

One way to date the beginning of the Renaissance is from May 29, 1453, the day the Turks captured the city of Constantinople and many Greek-speaking scholars escaped to the West. The scholars brought with them classical manuscripts in Greek along with the ability to translate the ancient writings into Latin, the common language of learning in Europe at the time. However, the roots of the Renaissance go back farther.

The end of the Middle Ages in western Europe was marked by a number of crises. The famine of 1315–17, the Hundred Years War between 1337 and 1453, the bubonic plague that killed the majority of people during that same period, and the resulting financial collapse slowed down development considerably. During those years the population of England dropped from 3,700,000 to 2,200,000, for example.

The Renaissance

After the depletion of the population of Europe in the 14th century from the Black Death, cities and towns rebounded with vigor. A population that is suddenly much smaller must find new ways to function. Mechanical devices and more trade made up to some extent for missing people. The new atmosphere encouraged the development of the arts, science, and technology. People searched to improve the utilitarian aspects of technology. States recognized the importance of technology for defense and trade and encouraged technological development. Kings engaged engineers to improve their fortifications

and weapons. Technology became fully accepted, and many artists (the best example is Leonardo da Vinci) became architects and technologists. Mathematics, now viewed as the basis of the arts (perspective) and technology, was introduced into universities. This era in full flower became the period we call the Renaissance.

Another factor at this time was the start of the Little Ice Age. Europe and Asia began to cool intensely about 1450 — although there was a lesser degree of cooling starting perhaps as early as 1150 and continuing until the end of the 19th century. The cooler climate was harmful in the far north, but seemed to invigorate trade and commerce in lower latitudes. Financial stability and an economic revival returned to western Europe around 1470, first south of the Alps and in Spain, later in the north. The crisis of the 14th and 15th centuries had also destroyed the feudal system of the Middle Ages, allowing the artisans and traders in the cities to gain power. A new type of owner took over. Land, mills, and manufacturing facilities were no longer owned by the church or a vassal, but by entrepreneurs, the early capitalists. When Martin Luther nailed his 95 Theses to the church door in Wittenberg in 1517, starting the Protestant Reformation, individual thought and capitalist enterprise received even more encouragement.

There was much change going on in the 15th and early 16th centuries for other reasons as well. Movable type was reinvented in Europe around 1440 and the Gutenberg 42-line Bible was printed just a year after the fall of Constantino-

ple. The Moors were driven from Spain the year that Columbus reached America, 1492. The European thrust eventually passed around the tip of Africa. In 1498 Vasco da Gama reached India by sailing around the Cape of Good Hope, linking Asia and Europe by water. By that time, Columbus had reached the Americas, completing the linkage of most of the globe. The period of exploration by ships from Portugal, Spain, Holland, and England revealed the civilizations of Africa and the Americas as well, adding to the known civilizations of Europe and Asia. These discoveries, however, resulted for many reasons in the destruction of the newly found states and the downfall of their peoples.

The 15th century was primarily a time of the absorption of classical learning and the adoption of Arabic mathematics. It was much more a period of change in arts and letters than in science. When one thinks of the Renaissance, one thinks of Leonardo da Vinci and Michelangelo, not Regiomontanus, Paracelsus, and Tartaglia. Alchemy and astrology were more important than chemistry and astronomy during this time. Physics had to reject Aristotle's work before it could develop the modern approach to physical motion.

Africa during the beginning part of this period included a number of independent kingdoms, notably Ghana and Mali in the western Savanna region and the Yoruba empire of Oyo, famed for its excellent metalworking. First the Arabs came from the east and the north, trading in goods and in slaves and also converting one ruler after another to Islam. Then the Portuguese and other Europeans came from the west and took

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over vast regions of the continent, sometimes, as in South Africa, as colonizers, but mostly as dominant rulers. Although Africa had strong metalworking and mining traditions, the African technology did not influence that of Europe; rather, it was the other way around.

In the larger sense of *feudal* it could be said that China, Japan, the Arab world, the African kingdoms, and the American empires were mostly feudal societies during this period. Kings and commoners had their place throughout most of the world, and society was stable and resistant to change. The transition from the feudal world to the modern one began in western Europe, some would say as early as the beginning of the 15th century, and was spread by exploration, conquest, and the printing press around the world.

The Renaissance, which began in Italy, reached northern Europe in the 16th century. There it joined with the new values of the Reformation. With the Renaissance came economic transformation: Markets were opened on a world scale and trade boomed in the cities. By 1603 the English philosopher and scientist Francis Bacon had characterized the new century as an age distinguished by “the opening of the world by navigation and commerce, and the further discovery of knowledge.” Bacon was among the first to view science as a powerful tool to conquer nature. In his fable *New Atlantis* he wrote that science’s aim is “the enlarging of the bounds of human empire; to the effecting of all things possible.”

But if it is barely possible to date the beginning of the Renaissance, it is almost impossible to say when the Renaissance ended. This is especially true for science. Gradually, scientists of the Renaissance began to perform experiments more frequently. The era of the Scientific Revolution that starts

in the later Renaissance also has no specific ending. We conclude this chapter just before the founding of England’s Royal Society, which inaugurates a new and better organized era in science dominated by Newton and Leibniz, an era in which the Scientific Revolution is completed.

The Scientific Revolution

Publication of Copernicus’s heliocentric theory and Vesalius’s anatomy in 1543 is a good beginning point for the Scientific Revolution. Throughout the West, modern science began to take shape in many ways.

Both the Catholic Church and the Protestant Church of Martin Luther opposed the views of Copernicus, but the Catholic Church persisted in its opposition and reaped most of the blame for unscientific attitudes. When the Inquisition burned Giordano Bruno in 1600 for his mystical heresies, it also appeared to condemn his Copernican views. By 1616, Copernicus’s *De revolutionibus* was on the Catholic Church’s Index of prohibited books, and Galileo was warned not to promote Copernican ideas. Galileo’s *Dialogues on Two Chief World Systems* was viewed as possibly concealing some of Bruno’s heresies and as breaking the ban on promoting Copernican views. The Catholic Church succeeded in forcing Galileo to abjure his Copernican beliefs in 1633. More than 100 years passed before the church allowed, in 1734, the construction of a mausoleum for Galileo. Much later the church lifted its ban on the publication of works that defended the Copernican system.

The explorers of both the New World and the East discovered a wealth of previously unknown plants and animals. Although the short-term effect was a sudden change in the diets of the peoples of Europe and Asia, the long-term importance was that these discov-

eries led to the classification schemes of John Ray and Carolus Linnaeus.

Throughout the period, mathematicians introduced various symbols and conventions, including the plus, minus, and times signs, letters for constants and variables, and raised numerals for exponents. Together this symbolism greatly simplified the communication of mathematical ideas. As the new expressions gained acceptance, they made mathematics an almost universal language. Not only were mathematical symbols beginning to make a difference, but the tools of mathematics expanded rapidly during the period. The new branches of the subject were symbolic algebra, analytic geometry, probability, and logarithms.

Mathematics is an intellectual tool of science, but the hardware of science also began to assume modern form during the period. The development of spectacles (eyeglasses) toward the end of the Middle Ages offered opportunities to experiment with lenses. In turn, this led to the invention of the telescope and the simple microscope around the beginning of the 17th century. Galileo’s observations of the stability of the beat of a pendulum led to Huygens’s invention of the pendulum clock. Galileo himself made one of the first thermometers.

Galileo also introduced experimentation into science, laying the foundation of science as we know it today. His detailed study of motion and his method of expressing natural events mathematically opened the way to Newton’s discovery of universal gravitation.

In the continuation of a trend that predates the Renaissance, artists, especially painters, made significant contributions to science. The development of perspective in drawing and the dissection of human bodies were valuable to both art and science. The artist Albrecht Dürer, for example, wrote papers on both geometry and anatomy.

The most notable example of the artist-scientist during this period was Leonardo da Vinci, a remarkable inventor and engineer as well as an artist skilled in human anatomy. Even the great artist Michelangelo functioned as an engineer in his design for the dome of St. Peter's and other buildings, as well as being in charge for a time of the fortification of Florence (Italy). From these people and others like them the term *Renaissance man* came to mean one skilled in many fields.

Technology

In technology, hints of a new world rising also were evident in the 15th century. A few pre-industrial factories operated. The earliest known assembly lines and industries based on interchangeable parts appeared (although some smelting and casting operations, even the first manufacture of uniform bricks, go back to late Neolithic times). Patent laws to protect inventions and the stock market, eventually a major means for financing technology, began. And, of course, printed books became the means to spread technological developments with unprecedented swiftness. Less obviously, the development of perspective was a step toward better drawings of machines and machine parts.

Several of the devices that would make mechanical calculators and machines with close tolerances of all kinds possible were invented during this period. Measurement was greatly improved, not only of lengths with the Vernier scale and the micrometer, but also of other qualities such as heat (various thermometers, including the pyrometer), humidity (the hygrometer), and air pressure (the barometer). Important auxiliary methods of transmitting motion or force included crank handles, drive belts, and foot treadles, all of which were to be of great impor-

tance in factories until the advent of small electric motors late in the 19th century. Better machine tools also began to appear during the 16th century, especially vastly improved lathes.

During the Renaissance the design of machines developed into an art. Several treatises appeared during that period, the so-called "machine books" or *theatrum machinorum*. Although still deeply rooted in the technical tradition of Antiquity and the Middle Ages, these books explored a wide variety of technical solutions, some of them realizable, some just dreams. Many of these proposed machines are what we would call gadgets, although sometimes of very large size. Automatons were very popular, and da Vinci, for example, designed and built a number of them. The German engineer Konrad Kyeser was the author of the first important machine book, *Belfortis*. It describes a number of devices, mostly military, such as catapults, guns, mobile bridges, and assault cars. In Italy, similar books were written by Brunellesco, Tacola, Robert Valturio, Leon Battista Alberti, and, best known of all, Leonardo da Vinci.

In France, the military engineer Agostino Ramelli produced in 1588 his *Various and Ingenious Machines*, a machine book that remained popular for a long time. It contains descriptions of automatons, such as hydraulic "singing birds," but also useful designs for practical machines. Ramelli was one of the first to describe a feedback system. He designed a feed hopper for mills that was propelled by the axis driving the grinding stone; consequently, the throughput of the hopper was proportional to the speed of the grinding stone. If there was not enough grain between the grinding stones, the mill accelerated, but also the throughput through the feed hopper was increased, feeding more grain to the grinding stones and slowing them down.

In the 16th century, similar hints of

the future included the first machines for turning a fiber into cloth (knitting in this case) and the development of better machine tools. It was only during the Scientific Revolution of the 16th and 17th centuries that science started playing a role in technical development. By the 17th century, a number of inventors were experimenting with steam, and the potential of steam as a source of power was recognized.

The 17th-century French philosopher Descartes, for example, considered the laws of nature to be the foundation of machines. In a letter to Christiaan Huygens, Descartes wrote that "you have to explain the laws of Nature and how She acts under normal circumstances before you can teach how She can be applied to effects to which She is not accustomed." Huygens soon did exactly that: Knowing that the period of a pendulum primarily depends on its length, he used the pendulum, modified to keep better time, to control the speed of clocks.

Major advances

ASTRONOMY The first great astronomical observatories began before the invention of the telescope, culminating in the observatory and work of Tycho Brahe. Galileo's introduction of the astronomical telescope in 1609 changed astronomy forever. Although Tycho Brahe rejected the work of Copernicus in favor of his own idiosyncratic system, his assistant and successor Kepler went beyond Copernicus to work out the detailed movements of the planets. Kepler also found empirical laws that govern these movements, laws that paved the way for Newton in the 17th century.

BIOLOGY There were also notable gains in botany. Scientists such as Otto Brunfels and Leonhard Fuchs published works, influenced by Latin translations of Aristotle and Theophrastus in which

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various plants were described or pictured. In the compendiums of Konrad Gesner, all known (and a few never to be known: Gesner still believed in mythical creatures) animals and plants were described. By the end of the 16th century, Gerard's *Herbal* stuck to real plants, but often ascribed almost magical properties to them.

CHEMISTRY Alchemists were probably making some progress in chemistry, but their interpretations of what they were doing and their tendency to keep results secret offered little to science. One chemical mixture that had originated in China had a great influence on Europe and the rest of the world during this period — gunpowder. Proven dates for improvements in gunpowder are hard to come by. Most recipes were probably kept secret.

COMMUNICATION The first scientific societies, such as the Academia Secretorum Naturae ("Academy of the Secrets of Nature") and the Accademia dei Lincei, were formed in Italy during this period. The former society was founded in 1560 but was soon suppressed by the Inquisition. The Accademia dei Lincei (the exact meaning of *Lincei* is not known; the academy's symbol is a lynx), founded in 1603, is the oldest existing scientific society.

COMPUTERS The first mechanical calculators were based on Napier's bones, a form of mechanical logarithm table, but Pascal developed mechanical calculators based on gear ratios. Pascal's calculators are similar in operation to those to come in the 19th and early 20th centuries. These early calculators did not have the benefit of parts made to high tolerances by modern machine tools, a problem that would also plague the first mechanical computers in the 19th century.

Automatons, which, of course, did not compute, continued to develop more and more elaborate programs. A

series of steps can be traced from the automaton through the music box to the Jacquard loom and player piano to the punched cards that were to program the first actual computers in the 20th century.

EARTH SCIENCE The main new understanding of Earth came from two sources: the exploration of nearly all of the world's landmasses and the introduction and understanding of Earth's magnetic field that began with the widespread introduction of the magnetic compass for navigation.

FOOD & AGRICULTURE Farmers introduced several new techniques that made agriculture much more effective. The plow replaced the much simpler ard and took on the form it has today. The most important improvement was that the new plows turned the earth over instead of merely cutting a groove in the soil. Turning over soil increases the fertility of the land by plowing in organic matter.

The second improvement in farming was the use of horses instead of oxen for working the fields. New breeds of horse, stronger and more resistant to disease, were introduced by the Berbers and spread through Europe. The padded shoulder collar and horseshoes made the horse much more efficient than the oxen.

The most important innovation in medieval agriculture was the introduction of crop rotation based on a three-year cycle. Traditionally, a two-year rotation cycle had been in use: One year the land was cultivated and the next year it was left alone. In the three-year cycle, the first year the land carried a winter crop, the second year a spring crop, and the third year it was left uncultivated.

Among the precursors of the Industrial Revolution was the roller mill, an improved form of water-powered mill for producing flour from grain.

MATERIALS Although iron in various forms was important, wood was still the basic material of the age. Besides its use in the production of iron and in heating, wood was also the main construction material for building houses, means of transport, ships, and even machines. Water wheels, windmills, gears, and camshafts were usually made from wood as well, although iron was used for reinforcement and for the reduction of friction in bearings. Tools such as shovels and plows continued to use iron edges on wooden bodies. Barrels made of wood were used for storage instead of the earthenware storage jars used in Greece and Rome in Antiquity, probably because the Mediterranean world did not enjoy the forests of the north.

Paper making, which had originated in China, spread throughout Europe during the first part of this period. Early paper was made from used fibers such as linen rags, not from wood, the source of most of today's paper. The manufacture of paper preceded the development of printing and made the invention of printing useful.

In Europe, people in what is now the Netherlands were the first to think of looking for coal underground. News of their success soon reached England, where coal mining became a major industry in the 17th century. Early in that century, also, the Englishman Hugh Platt became the first to heat coal and produce coke, a more satisfactory fuel for many purposes. For one thing, coke burns with a higher temperature than coal.

However, basic methods for preparing steel, cast iron, and wrought iron remained unchanged until coke was substituted for charcoal at the beginning of the 18th century. Until that time, metallurgy relied on charcoal, contributing to the severe deforestation in Europe during the years leading to the Industrial Revolution.

Commercial technology related to mining and smelting became important. This led to some of the early literature of technology, such as the works of Agricola and Biringuccio. With some other useful synergies, the Industrial Revolution was getting started.

Galileo, among many innovations, performed the first studies that could be classed as materials science.

MATHEMATICS As Hindu-Arabic numerals continued to replace the clumsy Roman system, various textbooks appeared that taught how to apply the new symbols. Standard algorithms and bookkeeping methods were introduced. Tables of trigonometric functions were printed and applied to new surveying techniques. Military uses of mathematics included ballistics and the improvement of fortifications. There was also gradual development of the symbolism of mathematics. All of these developments made mathematics easier and more a part of daily life.

On a more theoretical level, mathematicians were beginning to expand their understanding of what constitutes a number. Irrational numbers gained steady, if slow, acceptance as numbers, not merely magnitudes. Following the irrationals were the negatives. Even writers who refused to accept negative solutions to equations discovered that algebra could be greatly simplified by accepting negative coefficients. Soon the best mathematicians were using negative numbers regularly, but still expressing skepticism about them. Imaginary numbers began to have some currency later in the period.

A major achievement of mathematics during this period was the algebraic solution of the general cubic and quartic equations — that is, polynomial equations whose highest power of the unknown variable is three or four.

The publication of a new edition of the works of Diophantus led Fermat and his circle to advance pure number

theory. Much of their work was not published at the time. Similarly, probability theory was invented in an exchange of letters between Fermat and Pascal. Analytic geometry was developed by Fermat, who did not publish his discovery, and by Descartes, who published his finding in an appendix to a work of philosophy, the *Discourse on Method*.

MEDICINE & HEALTH Most of the progress in life science during this period was in medicine, especially anatomy. The invention of printing led to books on surgery and medicine. Although these books often contained many errors, knowledge of these subjects was much more widely available. Anatomy was based primarily on the works of Galen, especially at the beginning of the period, but the practice of dissecting corpses in front of medical students in Italy led careful observers to disagree with Galen by the end of the period.

Another factor in gaining a better understanding of anatomy was the study of musculature by painters and sculptors, notably Leonardo da Vinci. With the discovery of circulation of the blood by Harvey, a general picture of the body as a system of tubes, ducts, and valves grew during the course of the period. The mechanical view of the body became so prevalent that it acquired a name — iatromathematics, called iatrophysics today (*iatro-* means pertaining to medicine or healing). Also in the field of medicine, Paracelsus, heavily influenced by alchemy, became a strong advocate of the use of chemical medicines.

Another significant advance of the time is more problematical. Opium became the first painkiller since alcohol to enter general use. Like alcohol, and like most painkillers of any power since, opium was to prove a mixed blessing.

PHYSICS As with mathematics, much of the development of physical science

during the Renaissance had a strong practical side to it. Thus, we find advances and summaries of knowledge in such fields as mining, assaying, distillation, and ballistics. In the early part of the period, discoveries outside of practical fields were isolated instances.

A notable development took place when Galileo performed a series of experiments with moving bodies, making physics into an experimental science and founding the field of dynamics.

TOOLS The greatest technological innovation of the period was printing from movable type; however, this may be characterized as a reinvention. Movable type had been invented in the eleventh century by the Chinese, who had earlier invented printing. Chinese movable type was not a major influence, however, because ideographic writing is not as conducive to movable type as the Roman alphabet. Gutenberg probably did not get his idea from Chinese sources, even secondhand. His invention stems from about 1440, although the date is not certain. There is some evidence that movable type also was invented in Holland around the same time, which would suggest that the idea was generally known. Printing and paper, however, almost assuredly did reach the West from China, although indirectly. Thus, Gutenberg's reinvention of movable type was built on a Chinese foundation.

The most dramatic technological ideas of the early Renaissance come from Leonardo's notebooks. Penned in mirror-writing and illustrated with numerous sketches and drawings, the notebooks provide an unparalleled record of the thoughts of a man far ahead of his time. Leonardo is given some credit for the invention of the helicopter, the parachute, and other devices. In many cases it is not clear whether Leonardo made working models of his devices. Remarkable as his technical ideas were, they were mostly

The Renaissance and the Scientific Revolution: 1453 through 1659

secret and had little actual influence on the progress of science.

Advances in measuring devices and observational tools were another important technological feat of the period. Vacuum pumps, developed by Guericke and Boyle, also became tools of the new science. Clocks based on suspended weights and toothed escapements had been introduced in Europe about a century before, primarily as tower clocks that rang the hours. During the Renaissance there was constant improvement of their mechanisms. By the end of this period, there were small table clocks and even a sort of watch.

TRANSPORTATION Other technological innovations of the period furthered

understanding of space and time. Maps, needed by sailors following the routes of the great explorers, were improved. Globes were introduced even before the Americas were known in Europe. Astronomical navigation was improved around 1480 with increased use of the astrolabe by sailors to measure the positions of stars. More reliable maps included the Mercator projection, introducing a projection from a spherical surface onto a flat surface in such a way that angles and shapes remain preserved. Throughout the Renaissance, the difficulty of keeping accurate time severely limited the accuracy of navigation. This problem was not solved until the introduction dur-

ing the 18th century of clocks that could run on time on moving ships.

Near the beginning of the 15th century, lateen (triangular) sails were reintroduced, allowing ships to travel against the direction of the wind more easily. The basic way that boards were put together to make vessels was changed. Ships became progressively larger, and were equipped with superstructures and three masts. The caravel, the type of ship with which Columbus discovered America, appeared at the end of the 15th century, and the larger galleon during the 16th century. The improvement of ships made possible the great explorations of the 16th and 17th centuries.

CHRONICLE

1453

Communication

On May 29 the Ottoman Turks capture Constantinople. The flight of scholars from the city (bringing along Greek manuscripts) is often considered the start of the Renaissance period in Europe.

Construction

The Aqua Virgo aqueduct to Rome is put back in service by Pope Nicholas V, although it will continue to need major repairs from time to time. *See also* 537 CONS.

Earth science

Early in the year a large volcanic eruption occurs in the South Pacific, splitting apart an existing island and leaving parts now known as the islands of Tonoa, Epi, and Kuwae in the New Hebrides.

By May worldwide climatic effects reach Europe, where hail and flooding on May 25 contribute to the fall of Constantinople. *See also* 1815 EAR.

Tools

The Ottoman sultan Muhammad II uses the biggest cannon of the age, which fires balls weighing 270 kg (600 lb), to take Constantinople. *See also* 1378 TOOL; 1540 TOOL.

1454

Communication

Johann Gutenberg prints the 42-line Bible at Mainz (Germany), inaugurating the era of movable type about this date. Although there is considerable dispute concerning Gutenberg's printing innovations of the 15th century, the Bible is clearly his and a major milestone in printing history. The 1282-page, 42-line Bible, was set in type around 1452 and published in an edition of 300

copies before August 1456. *See also* 1440 COMM; 1457 COMM.

1455

Communication

Roberto Valturio [b. Rimini (Italy), 1405, d. 1475] writes his *De re militari*, completing it before 1460, a treatise on military machines, most of which had been conceived by his employer, Sigismond Malatesta. Printed at Verona in 1472, it is the first printed book with technical illustrations. *See also* 1405 TOOL.

1456

Astronomy

Paolo Toscanelli observes Comet Halley, the first recorded visit of the comet to Earth's neighborhood to be described in detail by a European writer. Although the comet was widely observed in 1066 in Europe, there was no scientific description. Visits in 1145, 1222, and

1378 were not recorded by European scholars. *See also* 1066 AST; 1472 AST.

1457

Communication

Printer and moneylender Johann Fust [b. Mainz (Germany), c. 1400, d. Paris, c. 1466], who has acquired Gutenberg's presses in repayment of debt, teams with Gutenberg's apprentice Peter Schoeffer [b. Bernsheim (Germany), c. 1425, d. Mainz (Germany), 1503] to print a Psalter using letters that incorporate both blue and red inks. The method remains a mystery until 1830, when William Congreve shows that Schoeffer used type made of two parts that fitted together but were inked separately. The firm of Fust & Schoeffer also pioneers in printing with Greek characters and will be the first printer to become successful financially. *See also* 1440 COMM; 1485 COMM.

L

Leas frus-natione auti-
censio-are mordit. vici-
pulu apofolos pofta
panli frouf wifd op con-
fessoris. Inimo dico fuit comme-
nam wifp wifom wifj habur neg-
line-hymagina et qranca amicu-
dito in bimina-plof spica fando.
Cui i am fcpita elift wifdatis. p-
wifdatis quide in ubra. p- maredi sur
in iaficatioris iufhigatu hinc in
achar parobs hcp fcpita xuanof-
gulat. pifor pifor jancit dafuq
lentum luci pofcentum ipi
leu luc pofcentum fum?

Onus quide mula co-
nan fuit ordinare nar-
ratus qid i nodis comp-
liter hci re. fuit rabi-
tis mula qid ab mulo
ipi uidebit. re mula
dicitu knomio et i mudi affec-
mula et propria uidebit. re mudi ob-
fuit opifit xophol: ut cognofas
con velon de flos radis et re tentat.

Vir in datus hodus et
go mudi facetus quidam
nomine zacharias de vi-
et abia-er uro illi de bila-
bila avon: et nomen rius zacharias.
Esti autem iusti ambu one druc-
iunctibus in omnibus mandatis i
iunctiunctibus domini fine quatta.
Et non reat ilios filios. et qd
de zacharias zacharias: et ambo pre-
fisteri datus suis. fadu et aut si fo-
rcetum lungemur zedatas in ordi-
ne p- fuit ante bre: fuit cuncto-
num facetus fore qid ut innotem
pouer ingulus in templi domini.
Et omnis mulendu qid reat trax fo-
re hoca inem. Apudic autem illi
angelus dui: Nam a brevis autem illi

GUTENBERG BIBLE The famous 42-line Bible printed by Johann Gutenberg was the first printed version of what became the world's most printed book.

→ Transportation

The first successful passenger coach, a four-wheeled wagon with a strap suspension, is built in Kocs, Hungary. Its design will spread through Europe in the 15th and 16th centuries; the name Kocs for the wagon will become "coach" when it reaches England. See also 1340 TRAN.

1458

→ Transportation

Following the plan first put forward by Bertola de Navate in 1451, the 19-km-long (12-mi-long) Bereguardo Canal is completed. Going from Abbiate to Bereguardo (Italy), the canal requires 18 locks and a land portage to get to the Pici-

no River, from which navigation is possible to Pavia. The 18 locks are used to cover an elevation of 24 m (80 ft). See also 1438 TRAN; 1485 TRAN.

1460

↳ Communication

Albert Pfister becomes the first printer to combine woodcuts with movable type on one page, with both the text and images printed in a single pass through the press. See also 1298 COMM.

♥ Medicine & health

Heinrich von Pfolspeundt writes *Bündt-Ertzney*, the first book on surgery to be published in Germany. See also 1360 MED; 1490 MED.

Q

inam. Et zedatas iufhano et ni-
dens: et nomen rius fip n. Et aut
ab illi agit. Et nomen zedatas
quoniam quoniam et deputata sua. Et
ueri tua zedates patet nbi filii: et
vocablo nome tuo iohannem et re
pudium obi et epulatio et mudi in
nominare rius gaudentur. Et nomen
magno etri filio: et vnu et fuit no-
bire. Et spica fuit expulster ali-
bus et vnu manu fur: et multo filio-
ni et coruere ab diu denu ipso.
Et ipi peder etri ipi et spica et vnu
fur etri conueterat corda pani in
filio: et inuidibis ar prudens in
fou: parcer dico plebi pedia. Et dico
zacharias ad angeli. Unde hoc loxi?
Ego mi finis fuit et uocu mura, profite
in diuis his. Et reliquias angelus
dixi. Ego sum gabriel qd alio ante
deum: et nullo sum loqui ab dico
autem et regi illi qd uocari diebile.
Quia no nra impudibis agud hunc
omni uelbi. Dico autem maria. Et
angela dui: hor mudi fomili uerdi
mudi. Et dicitur ab illa agit. Et
pros est maria in diuis illis abit
in iudicata qd zedatas ipi et amplio.
Egredit autem pomer loqui ad
alio. Et cognovit qd uolumen uide-
bit i amplio. Et ipi reat inuenio illi:
et pomer illi. Et fadu et ut im-
plum fuit dico offi et abit i domi-
na. Post hoc aut dico cognit zedates:
et reat uer mudi: et uocatur se mudi
quoniam diuino. Quia hec mudi te-
mimus: ut ueriu quoniam exigit au-
tere obprobriu nra more homines.
In uerit aut fera mudi angeli
gabriel a dico in ministru gallo cui
nomen gabriel: ab virginem depo-
fauit uero nra nome reat iofph: de
tuo tund: et nome virginis maria
a dico: et uolunt spicas nrae m-

Et inuidibis agit ad eam dico. Quia
grana plena: vis mudi bracteata au in
muidibis. Quae si audirentur uera sit
in fomina nra: et cogubat qualis
est illa fomina. Et am angelus ri-
pet nomen maria: inuenisti tu gran-
am apud dico. Et concepero in uero
et parcer filio: ut uocabis nomen rius
apud. Hic rei magnus: et huius alibi
uocabitur. Et dicit dico dico fe
dom band pomo tuo: et cognubis i
domo iacob in eternu: et cognubis i
nra finis. Dico autem maria ad angelum.
Eunomi fer ihu: quoniam uer non
cognobas: et reprobis angulus di
st. A. Spiritus fandu fupurior in
et ueriu alibi uocabitur abru. obi.
Iheros et qd nra et re fandu: uoca
bit filio. Et ecce zedates cognatu cu
et ipsa uocari filio i fandu ha. Et
huius mudi et regi illi qd uocari diebile.
Quia no nra impudibis agud hunc
omni uelbi. Dico autem maria. Et
angela dui: hor mudi fomili uerdi
mudi. Et dicitur ab illa agit. Et
pros est maria in diuis illis abit
in iudicata qd zedatas ipi et amplio.
Egredit autem pomer loqui ad
alio. Et cognovit qd uolumen uide-
bit i amplio. Et ipi reat inuenio illi:
et pomer illi. Et fadu et ut im-
plum fuit dico offi et abit i domi-
na. Post hoc aut dico cognit zedates: et reat
uver mudi: et uocatur se mudi
quoniam diuino. Quia hec mudi te-
mimus: ut ueriu quoniam exigit au-
tere obprobriu nra more homines.
In uerit aut fera mudi angeli
gabriel a dico in ministru gallo cui
nomen gabriel: ab virginem depo-
fauit uero nra nome reat iofph: de
tuo tund: et nome virginis maria
a dico: et uolunt spicas nrae m-

their design proves inadequate for larger cannon. Breech-loaded cannon do not become common until the latter part of the 19th century. See also 1845 TOOL.

1465

↳ Communication

Germans Conrad Sweynheim and Arnold Pannartz print the first book in Italy, at Subiaco. See also 1454 COMM; 1470 COMM.

1466

⊕ Earth science

Russian trader Afanassi Nikitin reaches India via Persia and returns in 1472. He publishes his experiences in *The Voyage of Afanassi Nikitin over Three Seas*. See also 1419 EAR.

1470

⊕ Chemistry

A deposit of alum is discovered in Tuscany, making the mineral more available to industries and experimenters in the West. See also 1300 CHEM.

↳ Communication

Gasparini's *Pergamensis epis-
tolarum libri* is the first book
printed in France. See also
1465 COMM; 1474 COMM.

Italian painter Piero della
Francesca [b. Borgo san
Sepolcro (Italy), c. 1410, d.
Borgo, October 12, 1492]
starts his book on perspective,
De perspectiva pigendi ("on
perspective in painting"). See
also 1436 COMM; 1639 MATH.

1461

↳ Communication

King Louis XI of France rein-
states the state-run postal sys-
tem in France. See also 1550
COMM.

Σ Mathematics

De triangulis omnimodis ("on triangles of all kinds") by
Regiomontanus [b. Johann
Müller, Königsberg (Germany), June 6, 1436, d. Rome,
July 8, 1476] is a major sum-
mary of trigonometry, includ-
ing the Law of Sines. It will
not be published until 1533.
See also 1533 MATH.

☒ Tools

The first small breech-loading
cannon are built, although

■ Construction

Francesco di Giorgio Martini [b. Siena (Italy), 1439, d. Siena, 1502] writes his *Trattati di architettura, ingegneria e arte militare* (“treatise on architecture, engineering, and the military art”), mainly known for its architectural contents.

Σ Mathematics

Italian artist and geometer Leon Battista Alberti publishes *Trattati in cifra* (“treatise on cipher”). It describes methods for coding and deciphering messages. *See also* 1379 COMM; 1474 MATH.

1471

★ Astronomy

Regiomontanus builds an observatory in Nuremberg and also establishes a printing press there. *See also* 1424 AST; 1576 AST.

1472

★ Astronomy

Regiomontanus makes a thorough scientific study of a comet. This comet is sometimes incorrectly identified as Comet Halley (Comet Halley had been observed by Paolo Toscanelli in 1456). The correct designation is Comet 1471 Y1. Paolo Toscanelli also observes and describes Comet 1471 Y1. *See also* 1456 AST; 1550 AST.

Theoricae novae planetarum (“new theory of the planets”), a version of Ptolemy’s *Almagest* by Austrian mathematician and astronomer Georg von Peurbach [b. Peurbach, near Vienna (Austria), May 30, 1423, d. April 8, 1461], is published posthu-

mously with the aid of Regiomontanus. Unlike Ptolemy, Peurbach considers the epicycles as controlled by the Sun. *See also* 140 CE AST; 1543 AST.

1473

▼ Medicine & health

The first complete edition of the Avicenna’s *Canon of Medicine* is printed in Milan. *See also* 1130 MED.

❀ Physics

Lucretius’s *De rerum natura* (“on the nature of things”) is printed from the single surviving copy found in 1417, making the atomic theory of Democritus known to scholars in the West. *See also* 1417 COMM.

1474

★ Astronomy

Regiomontanus’s *Ephemerides astronomiae* (“astronomical diary”) appears, although without the tables of solar declination that later editions will have. The additional tables make the *Ephemerides* much more useful to navigators. *See also* 1483 TRAN.

⌚ Communication

The Republic of Venice (Italy) adopts the first formal patent law, providing the first legal protection for inventors. *See also* 1421 TRAN; 1623 COMM.

William Caxton [b. Kent, England, c. 1422, d. London, 1491] prints the first book in English. *See also* 1470 COMM.

❀ Earth science

Paolo Toscanelli prepares a chart of the Atlantic Ocean

that is supposed to have convinced Christopher Columbus that the distance from Spain to Asia is much shorter than shown on other maps of the time — only 4000 km (2500 mi). The other maps are more nearly correct, but Columbus bases his plans on Toscanelli’s map. *See also* 1492 EAR.

Σ Mathematics

Sicco Simonetta publishes *Regulae ad extrahendum litteras zifferatas sine exemplo* (“rules for finding the letters in ciphers, with examples”), a short work outlining methods of deciphering codes. This is the first work to take ciphers beyond simple substitution schemes. About this time governments and the military begin to use codes extensively. *See also* 1470 MATH; 1500 COMM.

1478

Σ Mathematics

The *Treviso Arithmetic*, a list of rules for performing common calculations, becomes the first popular printed textbook in mathematics. *See also* 1542 MATH.

☒ Tools

The first attempt is made to develop a form of cannon-fired projectile that will explode on impact by using hollow balls filled with gunpowder. The resulting accidents cause this line of development to be abandoned until 1634, when increased strength of cannon walls makes the project feasible. *See also* 1500 TOOL.

✈ Transportation

On the orders of Louis XI of

France, the construction of a tunnel through Mont Viso at a height of 2000 meters (6500 ft) is started, connecting the Dauphiné and the domain of the Marquis de Saluces. It is the first such enterprise undertaken in its time. *See also* 40 BCE CONS; 1692 TRAN.

1480

☒ Tools

The flyer is added to the spinning wheel. *See also* 1280 TOOL.

↗ Transportation

Leonardo da Vinci describes a workable parachute. *See also* 1492 TRAN.



Leonardo da Vinci

[b. Vinci (Italy), April 15, 1452, d. Amboise, France, May 2, 1519]

Leonardo’s great reputation in science and invention is posthumous, based on the translation and publication of his coded notebooks in the late 19th and early 20th centuries. In his lifetime, in addition to his famous paintings, he was known for his engineering of canal locks, cathedrals, and engines of war. The notebooks reveal Leonardo’s correct interpretations of anatomy, explanations of physical concepts such as inertia, and sketches for working parachutes and helicopters, all well in advance of those ideas entering the scientific record.

The mystery of Leonardo da Vinci

The place of Leonardo in history as an artist and even as a scientist is well known. Many of his inventions, such as the helicopter, were only on paper, however. His actual achievements and contributions to the technology of his time are less well known and somewhat problematical. On the one hand, it is said that none of his ideas were practical, while on the other, it is said that his improvements in canal locks have been imitated ever since.

After striking success as a painter in his youth, Leonardo, at about age 30, began to take commissions in fields that we would today identify as architecture or engineering. From then on, he made at least part of his living designing improvements on buildings and canals, some of which he then built and some of which languished. Increasingly he designed in secret devices that anticipated flight, steam power, and much more.

Much of the reason for the apparent mystery of his ideas about technology is that he wrote and drew them in coded notebooks that, although he worked on them for much of his adult life, were never sufficiently organized to decode and publish. Indeed, most pages of the notebooks were not published until late in the 19th century. All his life he found it difficult to complete a task, even abandoning paintings for which he had been

paid. Single pages of the famous notebooks, although nearly all written so that each deals with a separate chain of thought, often slip from one topic to another.

Among the public achievements that contributed to the technology of his time are the maps of Italy he made at the beginning of the 16th century. Although none of his architectural plans were executed, many were known at the time and became a major influence on such buildings as St. Peter's in Rome. In addition to canal lock gates, replacements in 1497 for worn-out gates on the oldest canal in Italy, it is thought that he actually built a screw-cutting machine and a turret windmill, both advanced for the time and not followed by others until much later. Some give Leonardo partial credit (along with Palladio) for the truss bridge, but trusses were occasionally used by the Romans and did not become common in bridges until centuries after Leonardo's death.

It is thought that some may have seen his notebooks and been influenced, notably Girolamo Cardano, but that is not certain. If they had been, we might have earlier had the advantage of Leonardo's experiments with tensile strength, his analysis of forces produced by arches and hoisting devices, and his work on the strength of beams and columns. A half century after Leonardo's death, another great Italian, Galileo, repeated such experiments and analyses — and published them in a clear, coherent form.

1482

Σ Mathematics

Erhard Ratdolt [b. Augsburg (Germany), 1447, d. Augsburg, 1527] produces the first printed edition of Euclid's *Elements*, a Latin translation by Johannes Campanus. This is the first mathematical book of significance to appear in print (as opposed to handwritten form) and also the first printed book illustrated with geometric figures. *See also* 1260 MATH.

1483

★ Astronomy

The *Alfonsine Tables*, a revision of the Ptolemaic tables of the planetary positions created in

Toledo about 1250, are printed in Toledo. *See also* 1272 AST.

→ Transportation

The first known tables of solar positions, for navigational purposes, are printed in Venice. *See also* 1474 AST; 1484 TRAN.

1484

Σ Mathematics

Triparty en la sciences des nombres ("knowledge of numbers in three parts") by Nicolas Chuquet [b. Paris, 1445, d. Lyon, France, 1488] is the first book on algebra to permit a negative root to an equation. However, Chuquet does not accept zero as a solution and views imaginary numbers as *ineperible* ("absurd"). He also introduces

multiplication tables. *See also* 628 MATH; 1545 MATH.

→ Transportation

Portuguese sailors start using a table of solar heights above the Iberian peninsula compiled by Spanish astronomer Abraham Zacuto [b. Castile, 1452, d. 1525] to determine latitude by measuring the height of the noonday Sun. *See also* 1483 TRAN.

1485

↳ Communication

Erhard Ratdolt prints an edition of Johannes de Sacrobosco's astronomy book *Tractatus de spheara* ("a treatment of spheres"), the first printed book to use several differently colored inks on the same

page. *See also* 1457 COMM; 1710 COMM.

The first decrees for the prohibition of books perceived as dangerous appear in Mainz (Germany). *See also* 1559 COMM.

■ Construction

De re aedificatoria ("on the art of building") by Leon Battista Alberti, on construction methods and architecture, is published. Written some 30 or 40 years earlier, it gives scientific rules that should be followed in construction, but also emphasizes the art of architecture. *See also* 1436 COMM.

→ Transportation

Leon Battista Alberti's *De re aedificatoria* contains the first printed description of a canal lock. *See also* 1458 TRAN.

1486**Construction**

The long-lost manuscript of *De architectura* ("on architecture") by Roman architect Vitruvius is published. It becomes the key influence on architecture for the 16th century. *See also* 1415 CONS.

1488**Transportation**

Portuguese explorer Bartholomeu Dias [b. c. 1450, d. Atlantic Ocean, May 29, 1500] in January rounds the Cape of Good Hope at the southern tip of Africa, completing a series of voyages down the west coast of Africa that had started in 1433. He becomes the first European sailor known to have sailed around the Cape of Good Hope. *See also* 1419 EAR; 1498 TRAN.

1489**Mathematics**

Behend un Hüpsch Rechnung uff allen Kauffmanschafften ("mercantile arithmetic") by lecturer Johann Widmann [b. (Germany), 1462, d. 1498] is the first printed document to use the familiar signs + and -. However, Widmann uses them to mean a surplus (+) or a deficit (-). *See also* 1514 MATH.

1490**Energy**

Leonardo da Vinci develops an oil lamp with a glass chimney that also acts as a lens, concentrating the light for use in reading at night.

Medicine & health

The Chinese invent the modern form of toothbrush with pig bristles at a right angle to the handle.

An "anatomical theater" is opened in Padua by A. Benedetti Da Legnano for

demonstrating the dissection of corpses. *See also* 1460 MED; 1497 MED.

Physics

Leonardo da Vinci notes that some liquids in tubes with a small diameter tend to crawl up the tubes, the first notice of capillary action.

Tools

Martin Behaim [b. Nuremberg, Germany, 1459, d. Lisbon, Portugal, August 29, 1507] adapts the astrolabe for use in determining latitude. *See also* 1391 TOOL.

1491**Mathematics**

Filippo Calandri's arithmetic text introduces the commonly used algorithm for long division. *See also* 1659 MATH.

1492**Communication**

Martin Behaim makes the first

globe map of Earth, omitting the about to be discovered Americas and Pacific Ocean. *See also* 1490 TOOL; 1515 COMM.

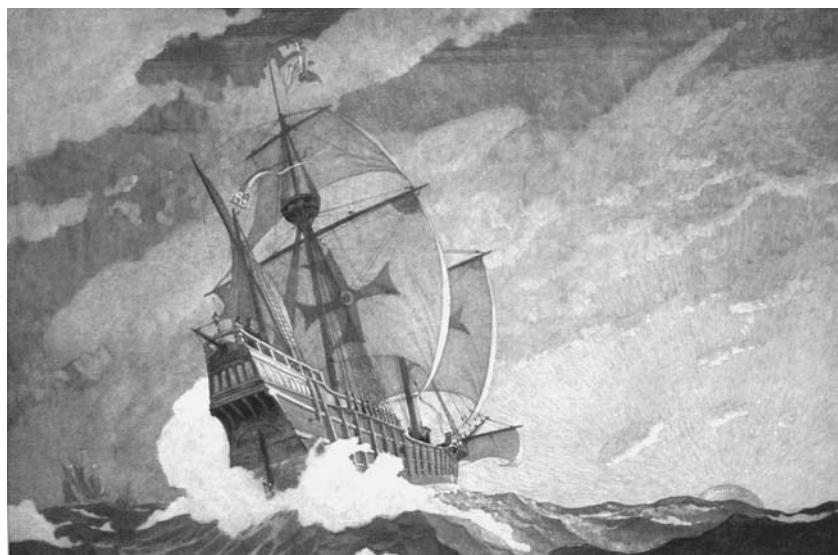
Earth science

On October 12 Christopher Columbus (Cristoforo Colombo) [b. Genoa (Italy), 1451, d. Valladolid, Spain, May 20, 1506] lands on an island in the Caribbean Sea. This is considered the principal European "discovery" of America, although certainly preceded by Viking contacts and possibly by other Europeans. *See also* 1493 MATR.

Columbus discovers on his first voyage to the Americas that the magnetic compass somewhat changes the direction in which it points as the longitude changes. *See also* 1530 EAR.

Materials

Graphite, known commonly as lead, is used for writing around this time in England. *See also* 1565 MATR.



COLUMBUS CROSSING ATLANTIC The three famous ships, the *Nina*, *Pinta*, and *Santa María*, in which Columbus and his crew crossed the Atlantic from Spain to the Caribbean Islands, were all less than 25 m (80 ft) long and 9 m (30 ft) wide.

Σ Mathematics

Francisco Pellos's *Compendio de lo abaco*, a commercial arithmetic, introduces a dot to represent division by 10, a precursor of the decimal point. *See also* 1525 MATH.

→ Transportation

Leonardo da Vinci draws his conception of a flying machine. *See also* 1500 TRAN.

1493

⊕ Earth science

Pope Alexander VI on May 4 draws a line on a map that gives Spain all the undiscovered lands to the west of the line and Portugal all the undiscovered lands to the east of it; subsequently the line will be moved in such a way as to give Portugal the right to claim Brazil.

◊ Materials

On his second voyage, Christopher Columbus discovers that Native Americans produce balls that bounce; the balls are made from a coagulated and dried sap of a tree. Today we know this product as rubber. *See also* 1492 EAR.

♥ Medicine & health

Christopher Columbus on his second voyage finds that American natives use tobacco as a medicine. *See also* 5000 BCE FOOD; 1497 MED.

1494

◊ Materials

The first paper mill appears in England. *See also* 1391 MATR; 1666 MATR.

Σ Mathematics

Summa de arithmeticā geometriā proportioni et proportionālita ("the whole of arithmetic, geometry, ratio, and proportion") by Luca Pacioli [b. San Sepolcro (Italy), c. 1445, d. San Sepolcro, 1517], the first printed book on algebra in Europe, will be the most influential mathematics book of its time. Derived largely from Fibonacci's *Liber abaci*, published 300 years earlier, its popularity may be owed to its introduction of double-entry bookkeeping. *See also* 1202 MATH.

I Tools

Leonardo da Vinci makes a drawing of a clock with a pendulum. *See also* 1581 PHY.

1495

◊ Materials

The first cast-iron cannonballs are used in the conquest of the Kingdom of Naples by France according to Vannoccio Biringuccio [b. Siena (Italy), October 20, 1480, d. 1538 or 39], writing about 40 years later. *See also* 1380 MATR; 1540 MATR.

♥ Medicine & health

As the French army of Charles VIII takes Naples, camp followers of the defending Spaniards infect his troops with syphilis. The army then moves back to France, infecting the Italian peninsula and northern Europe. The theory that the disease was brought to Spain from the Americas by sailors on Columbus's voyages has been discredited by evidence for cases observed in remains of pre-Columbian Europeans. *See also* 1530 MED.

1496

↳ Communication

Michel de Toulouze's *L'art et instruction de bien dancer* ("the art and teaching of good dancing") includes the first printing of music combined with a text set with movable type. Red staffs are printed on one pass through the press and notes in black type on a second pass.

I Tools

Leonardo da Vinci designs roller bearings and a rolling mill. *See also* 1790 MATR.

1497

★ Astronomy

Nicolaus Copernicus observes and records the occultation of a star by the Moon; that is, the Moon passes in front of the star, hiding it. *See also* 1976 AST.



Nicolaus Copernicus

[b. Toruń, Poland, February 19, 1473, d. Frombork, Poland, May 24, 1543]

Copernicus was a scholarly church canon who succeeded in convincing almost all later astronomers that Earth rotates on an axis and revolves about the Sun. Aristarchus, an early Greek, had proposed similar ideas, but few accepted them. The ideas expressed by Copernicus were not exactly what we believe today — for example, Copernicus used circles moving on circles to make his system work. Elliptical orbits were not recognized as possible until a century later.

↳ Communication

The first English almanac, translated from French, is published in England. *See also* 1680 AST.

♥ Medicine & health

The monk Romano Pane, who accompanied Columbus, gives a description of the tobacco plant and the smoking habits of the Indians. *See also* 1493 MED; 1507 MED.

Hieronymus Brunschwyk [b. c. 1452, d. 1512] publishes the first known book on the surgical treatment of gunshot wounds. *See also* 1490 MED; 1500 MED.

→ Transportation

In one of his few engineering feats that influence developments of his time, Leonardo da Vinci designs new gates for locks on the parts of the Naviglio Grande within Milan itself. The new gates are of the miter type and can be folded back into recesses in the walls when the locks are open, creating more room for ships. With a different placement for the water discharge, the new arrangement occupies about a sixth of the space of previous gates and will be used on locks even today. *See also* 1438 TRAN.

1498

↳ Communication

Aldus Manutius [b. Bassiano (Italy), c. 1469, d. Venice, 1515] completes a Latin translation of Aristotle's works. *See also* 1260 COMM.

Venetian printer Ottaviano dei Petrucci [b. June 18, 1466, d. May 1539] invents a way of printing music using movable type. *See also* 1496 COMM.

1498–1499

✈ Transportation

Portuguese navigator Vasco da Gama [b. Sines, Portugal, c. 1469, d. Cochin, India, December 24, 1524] becomes the first European to sail to India by rounding Africa, arriving in May. Only 54 of the 170 who start the trip return to Portugal in 1499. *See also* 1488 TRAN.

1499

❖ Materials

Polydore Vergil [b. Urbino (Italy), c 1475, d. Urbino, 1555] writes *De inventoribus rerum* ("on the inventors of things"), one of the earliest compilations discussing inventors and their inventions, including gunpowder, glass, printing, and ships. *See also* 1420 TOOL; 1588 TOOL.

1500

☛ Communication

By the end of the 15th century, about 35,000 different books have been published and printed. The total number of copies produced is estimated at 20,000,000 About 77 percent of the books are in Latin while 45 percent deal with religion. *See also* 1440 COMM.

Johannes Trithemius of Spanheim [b. 1462, d. Würzburg (Germany), 1516] writes *Steganographia* ("hidden writing"). Copies of the manuscript circulate for a hundred years. *See also* 1474 MATH; 1553 COMM.

❀ Earth science

Leonardo da Vinci, who finds many fossils in canal building sites, proposes that fossil shells

of marine animals are found on mountains because Earth undergoes transformations that cause areas once submerged under water to become exposed. *See also* 1250 EAR; 1517 EAR.

☛ Energy

Gravity-powered water systems for towns are in use. *See also* 1600 TOOL.

❖ Materials

Hieronymus Brunschwygk's *Liber de arte distillandi de simplicibus*, known as the "Small Book" or as "The Little Book of Distillation," describes the construction of furnaces and stills, herbs usable for distillation, and medical applications of distillates. He will publish his "Big Book," dealing with the same subjects, in 1512.

♥ Medicine & health

Jakob Nufer, a Swiss pig gelder, performs the first recorded cesarean operation on a living woman. *See also* 1497 MED; 1545 MED.

I Tools

Leonardo da Vinci draws a wheel-lock musket, the first known appearance of this type of ignition, which will come into use about 15 years later. Earlier small arms had been ignited by various forms of matches; the wheel-lock is ignited when a spring mechanism causes a ratchet to strike sparks from iron and pyrites or flint. *See also* 1515 TOOL.

Rifling in gun barrels is introduced. Grooves are cut in spirals into the interior of the barrels, imparting a stabilizing spin to the projectile.

✈ Transportation

Leonardo da Vinci designs the

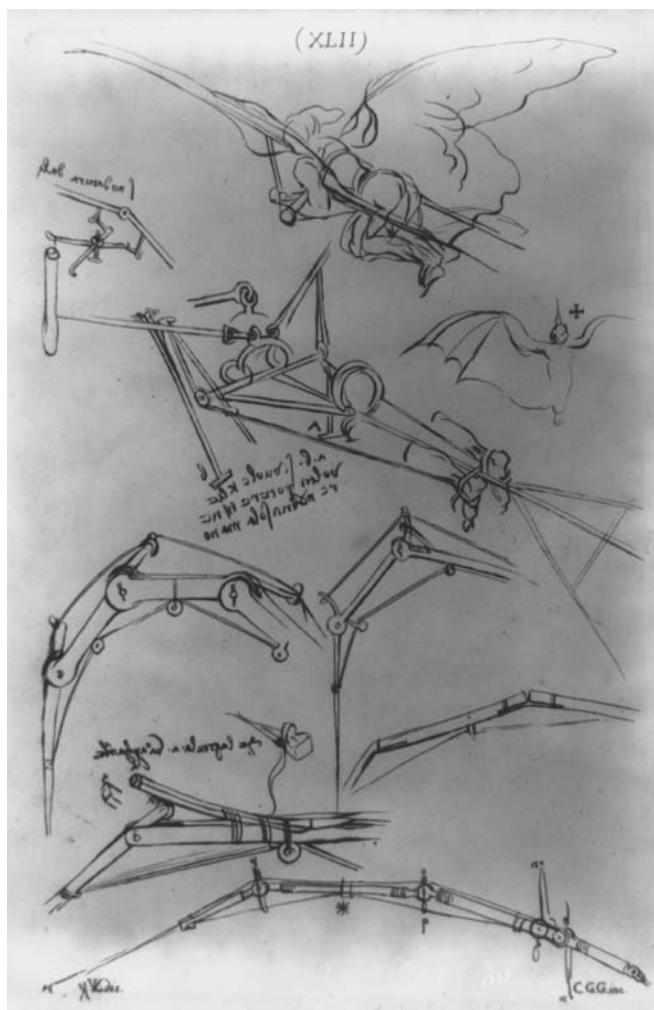
first helicopter. It is not built and probably would not have flown if built. *See also* 1492 TRAN.

Chinese scientist Wan Hu ties 47 gunpowder rockets to the back of a chair in an effort to build a flying machine. The device explodes during testing, killing Wan, who acted as pilot. *See also* 1150 TRAN.

1502

☛ Energy

Leonardo da Vinci designs a windmill with a revolving turret, and may have built one at Cesena (Italy). About 50 years earlier the Dutch were already using windmills with turrets. *See also* 1450 ENER.



LEONARDO'S FLYING MACHINE In addition to a helicopter, Leonardo also drew sketches of a device for flying like a bird, by flapping wings — later termed an *ornithopter*. Engineers, while admiring Leonardo's design, have since established that human muscles are not strong enough to power an ornithopter.

I Tools

Peter Henlein [b. Nuremberg (Germany), c. 1485, d. Nuremberg, September 1542] builds a spring-driven watch, one of the first clocks ever built that is intended to be carried about (called a watch because it was first used by watchmen). The Henlein clock, nicknamed “the Nuremberg egg,” is about the size of a softball and has only one hand. Sometimes called a pocket watch, it is on a chain like a pocket watch but worn with the chain around the neck. *See also* 1364 TOOL; 1658 TOOL.

1503

■ Construction

Pope Julius II chooses Donato Bramante (d'Agnolo) [b. Monte Asdrualdo (Italy), c. 1444, d. Rome, March 11, 1514] to design and rebuild St. Peter's Church on the ruins of an early Christian basilica, which Bramante designs hastily with many errors that are compounded by various reworkings by a succession of popes between 1514 and 1546. *See also* 1546 CONS.

■ Food & agriculture

Raw sugar is refined.

1504

★ Astronomy

Christopher Columbus, using an edition of Regiomontanus's *Ephemerides astronomiae*, frightens a group of Native Americans by correctly predicting a total eclipse of the Moon on February 29.

▼ Energy

The *Codex Leicester* describes a device for measuring the expansion of steam. The device consists of a vessel covered with a cow hide and a metal top that is counterbalanced by a weight; boiling the water in the vessel lifts the hide, which pushes the top up. However, no reference to the possibility of steam power is made. *See also* 1606 ENER.

1505

◊ Materials

Bergbüchlein (“booklet on mining”), which will be reprinted five times before 1540, is published. *See also* 1556 MATR.

1507

↳ Communication

German cartographer Martin Waldseemüller [b. Baden (Germany), c. 1470, d. Alsace (France), c. 1518] publishes a thousand copies of a map on which the name America is first applied to the new continent discovered by Columbus and explored by Amerigo Vespucci (Americus Vespuccius) [b. Florence (Italy), March, 1454, d. Seville, Spain, February 22, 1512] between

1497 and 1504. Unlike Columbus, Vespucci recognizes that he is exploring a new continent and not part of Asia.

■ Construction

The Pont Notre Dame in Paris, designed by Fra Giocondo [b. Verona (Italy), c. 1445, d. Venice (Italy), c. 1525], connects La Cité Island with the north bank of the Seine. *See also* 1607 CONS.

▼ Medicine & health

Cosmographiae by Martin Waldseemüller contains the first printed allusion to tobacco. *See also* 1497 MED; 1550 MED.

1508

▼ Medicine & health

German knight Gotz von Berlichingen [b. 1480, d. 1562] makes a prosthetic hand with flexible finger joints to replace the one he lost in the battle of Landshut.

1512

⊕ Earth science

The Portuguese explorers de Abreu and Serrao reach the Moluccas, or Spice Islands.

Σ Mathematics

French soldiers massacre Italians who have fled to the Brescia cathedral for sanctuary; among the dead is the father of the wounded Niccoló Fontana. As a result of his saber wound, the young boy develops a stammer that causes him — a mathematical genius — to be known to posterity as Niccoló Tartaglia (stutterer).



Tartaglia (Niccolò Fontana)

[b. Brescia (Italy), 1499, d. Venice, December 13, 1577]

Tartaglia is known mainly as the first to solve the general equation of a polynomial of degree 3 (the cubic). He also developed the rule that an elevation of 45° for a cannon provides the maximum-distance shot. He was the first to publish Pascal's triangle in Europe and translated Euclid into Italian and some of Archimedes into Latin.



FIRST MAP NAMING AMERICA An insert on Waldseemüller's map of the world shows a surprisingly accurate South America (since its west coast had not been explored in 1506) along with an image of Amerigo Vespucci. It is clear that Waldseemüller recognized that the Americas were not the eastern part of Asia, as Columbus had believed.

1513

Communication

Martin Waldseemüller prepares an atlas containing 200 maps. *See also* 1507 COMM.

Earth science

Explorer Vasco Núñez de Balboa [b. Jerez de los Caballeros, Spain, 1475, d. Panama, 1517] becomes the first European to discover the Pacific Ocean, which he names Mar del Sur ("south sea").

Ponce de León [b. (Spain) 1460, d. 1521] is the first sailor to write about his observation of the Gulf Stream off the coast of Florida.

Tools

An instrument called a polimetrum is used to make a field survey of a region in the upper Rhineland (Germany), from which a map is drawn. *See also* 1533 MATH.

1514

Astronomy

In May Copernicus writes his first version of his heliocentric theory, which he does not publish until 1543. *See also* 1540 AST.

Communication

Brothers Joannes and Gregorius De Gregoriis at Fano (Italy) print the first book with Arab characters. *See also* 1457 COMM.

Food & agriculture

Pope Julius de Medici hires Leonardo da Vinci to drain the 775-sq-km (300-sq-mi) Pontine Marshes southwest of Rome. Although Leonardo prepares a bold and practical plan, the pope dies before any of it can be carried out. *See also* 1590 FOOD.

Mathematics

Dutch mathematician Giel Vander Hoecke is the first to use the signs + and – with their modern meanings in an

algebraic expression. *See also* 1489 MATH; 1557 MATH.

Physics

Summa in totam physicam, hoc est philosophiam naturalem by German scholar Jodocus Trutfetter [b. 1460, d. 1519] is an account of Theodosius of Freiburg's work on the rainbow. This book probably inspired Descartes in his research on the rainbow. *See also* 1304 PHY; 1637 EAR.

1515

Communication

Geographer and mathematician Johannes Schöner [b. Karlstadt (Germany), January 16, 1477, d. Nuremberg (Germany), January 16, 1547] is the first to construct a globe showing the Americas.

Mathematics

Scipione del Ferro [b. Bologna (Italy), February 6, 1465, d. Bologna, November 5, 1526] discovers and keeps secret a

method for solving one type of cubic equation.

Tools

The wheel-lock musket begins to be manufactured. It is recognized as an improvement over the matchlock, which is difficult to operate in damp weather, although the matchlock continues to be used in many weapons because of its simplicity. *See also* 1500 TOOL; 1625 TOOL.

1516

Communication

Henry VIII appoints the first Master of the Post, thus establishing an official postal service. *See also* 1464 COMM; 1550 COMM.

1517

Earth science

Girolamo Fracastoro [b. Verona (Italy), 1478, d. Verona, August 8, 1553] explains fossils as the remains of actual organisms.

Inventing signs

Today the language of mathematics is in many ways standardized around the world. A Japanese mathematics book can almost be read by an American mathematician who knows no Japanese. Furthermore, we have become used to the idea that mathematics is a kind of special language, one made up of letters and signs. This notion of mathematics as a language ignores the fact that much excellent mathematics dates to classical and Hellenistic times, before this language of signs and symbols was invented.

Although the signs + and – were used in the 15th century to denote surpluses and deficits, they were not given their modern meaning until 1514. Our present day = sign was introduced in a slightly different form in 1557. In 1593 letters were used to represent variables. The year 1631 saw rival introductions of · and × for

multiplication, a rivalry that continues today. By 1659 the ÷ sign was present.

The importance of apt signs in mathematics is best illustrated with the calculus. Both Newton and Leibniz discovered the ideas of the calculus, and both invented a method to write down their calculations and results. Newton's way was to put dots and primes above the variables and to use o for an infinitesimal. Leibniz invented the notation dy/dx and the integral sign. In England, mathematicians used Newton's symbolism, while on the Continent, they followed Leibniz. For a century after Newton there was little English mathematics of consequence. Only after British mathematicians relented and adopted the Leibniz notation did British mathematics regain its position. This did not begin until after 1815, when the Analytical Society was formed at Cambridge with the express purpose of replacing the clumsy Newtonian notation with that of Leibniz.

Fossils: organisms turned to rock

From earliest times people must have seen fossils — remnants of organisms of the past preserved in various ways — but the first reports we have on the subject are from the ancient Greeks. Xenophanes of the early Ionian school is said to have noticed fossilized sea creatures high on mountains; he correctly interpreted this as meaning that these mountains had once been under water. Later, Herodotus reached the same conclusion regarding fossilized clam shells on mountains, but he misinterpreted other fossils. For example, he equated the fossilized bones of large creatures with mythical animals or with giant humans. Theophrastus, Aristotle's successor at Lyceum, is said to have written a book on fossils, but it is lost, although in one of his works that has been preserved he refers to fossil fishes. It appears that Theophrastus thought that fossil fishes had become dried out by being trapped in sand. A recent theory is that some of the "monsters" depicted on Greek vases are based on fossil bones and imaginative reconstructions. In Roman times, Suetonius casually mentions that the emperor Augustus kept a collection of large fossil bones at his villa. These scattered references suggest that observers in Antiquity recognized that fossils are remains of organisms. At the same time they suspected nothing of the very ancient origins of fossils.

The Arab scholar Avicenna put forward an idea that was to confuse people about fossils for centuries. He argued against the concepts of alchemy, especially against the idea that one metal could be turned into another. But he extended the argument to oppose the idea of bone turning into rock. Most ancient fossils are petrified: The original living tissue has been replaced by rock.

Avicenna was right in saying that bone does not turn into rock, since the bone is replaced, but wrong in arguing that this implies that fossils cannot have an organic origin.

The word fossil was coined by Georgius Agricola in the 16th century to mean anything dug up. Although Agricola was writing primarily about mining metals, he also described what we would still call fossils today. These were all fossil sea creatures, but Agricola lived most of his life far from the sea. Not only did he not know that his part of Europe had once been covered with shallow seas, but he was unfamiliar with living sea creatures. Agricola thought that the fossils were just stones that occur in particular shapes, rather as crystals do.

Writing about ten years later than Agricola, Konrad von Gesner picked up Agricola's new word and classified fossils into 15 different types. Although Gesner was acquainted with creatures of the sea, he failed to differentiate between real fossils of organic origin and other "shaped rocks."

Ten years later, Bernard Palissy began to lecture on the natural world. He used fossils as props for his talks. Unlike Agricola and Gesner, Palissy recognized that fossils are remains of living organisms. Throughout the 16th century, scholars, including Jerome Cardan, Andrea Cesalpino, and Gabriel Fallopio, debated the nature of fossils.

In the 17th century, Nicolaus Steno and Robert Hooke argued persuasively that fossils are remains of living organisms, with Steno correctly identifying the origin of many common fossils, such as sharks' teeth. Of course, some fossils were of extinct creatures, but not even Steno realized this. Athanasius Kircher may have been the first to suggest the possibility of extinct species when he proposed that some animals failed to make it onto Noah's ark.

He notes that while some could have been buried in Noah's Flood, they are at too many different geologic strata for all of them to have been caused by a flood that lasted only 150 days. *See also* 1500 EAR.

1518

Heart Medicine & health

Physician and humanist Thomas Linacre [b. Canterbury, England, 1460, d. London, October 20, 1524], with a charter from Henry VIII, founds of the Royal College of Physicians in London.

1520

Communication

German astronomer Peter Apian (Petrus Apianus) [b. Leisnig (Germany), April 16, 1495, d. Ingolstadt (Germany), April 21, 1552] publishes a map that shows the American continents. *See also* 1507 COMM.

Food & agriculture

Turkeys are imported to Europe from America along with maize (corn) from the West Indies and the orange tree from south China.

Materials

Probierbüchen ("little book of assays"), which will become the main guide to assaying metals, is published. *See also* 1540 MATR.

Heart Medicine & health

Physician and alchemist Philippus Aureolus Paracelsus (Theophrastus Bombast von Hohenheim) [b. Schwyz (Switzerland), May 1, 1493, d. Salzburg, Austria, September 24, 1541] introduces tincture of opium, which he names laudanum.

Tools

Spinning wheels powered by

foot treadles come into use. *See also* 1480 TOOL; 1530 TOOL.

1522

Earth science

Spanish navigator Juan Sebastián del Cano [b. Guevaria (Spain) c. 1460, d. Pacific Ocean, August 4, 1526 on his second voyage to the Pacific] completes the first voyage around Earth after original commander Fernando Magellan is killed. *See also* 1492 EAR.

Paracelsus contends that external agents cause disease and argues that chemicals can be used to fight and cure such diseases. *See also* 1520 MED.

1524

↳ Communication

German astronomer Peter Apian publishes a book on cartographical methods. *See also* 1513 COMM; 1533 MATH.

1525

Σ Mathematics

Die coss ("the variable," i.e. x) by German mathematician Christoff Rudolff [b. Jauer, Silesia (Poland), c. 1499, d. Vienna (Austria), 1545] introduces a version of the modern symbol for the square root, $\sqrt{}$, and is one of the earliest books to use decimal fractions. *See also* 1492 MATH.

Artist Albrecht Dürer [b. Nuremberg (Germany), May 21, 1471, d. Nuremberg, April 6, 1528] writes a book on geometric constructions, including proofs of how to construct complicated curves.

♥ Medicine & health

The European disease smallpox reaches the Inca Empire, killing Huayna Capac, the Inca emperor.

1526

↳ Communication

Jacopo Silvestri writes *Opus novum . . . principibus maxime utilissimum pro cipheris* discussing six cipher methods, including the use of a cipher disk for the Caesar cipher (a code that simply substitutes a letter the same distance in the alphabet for each letter in the message; Seutonius reported that a code employed by Julius Caesar to write to friends used the letter three places down).

✳ Ecology & the environment

Paracelsus writes about this time that "miner's disease" (silicosis) is caused by inhaling metallic dust — not, as widely believed, by spirits as punishment for sins. *See also* 1525 MED.

1527

✳ Food & agriculture

Archidoxis by Paracelsus (not published until 1570) reports that frozen wine will have a higher proof than liquid left unfrozen, meaning that the unfrozen portion of the liquid will have a higher alcohol content, since alcohol has a higher freezing point than water. *See also* 1100 FOOD.

Σ Mathematics

The arrangement of counting numbers known as Pascal's triangle appears for the first time in Europe as the frontispiece of a book by Peter Apian. *See also* 1303 MATH; 1654 MATH.

1530

✳ Biology

Herbarum vivae eicones ("living portraits of plants") by Otto Brunfels [b. Mainz (Germany), 1488, d. Bern, Switzerland, 1534] describes 230 species of plants with detailed illustrations drawn by Hans Weiditz.

✳ Earth science

In Spain, Alonso de Santa Cruz produces the first map of magnetic variations from true north; he thinks this may aid in finding the correct longitude. *See also* 1492 EAR; 1544 EAR.

↗ Energy

There are reports of matches being used in Europe, almost a thousand years after their invention in China. The European matches are tipped with some chemical that ignites easily, perhaps when brought into contact with or removed from another chemical (it is not clear how the Chinese matches worked). *See also* 568 ENER; 1827 ENER.

♥ Medicine & health

Girolamo Fracastoro's *Syphilis sive de morbo gallico* ("on syphilis, or the French disease") describes the symptoms, spread, and treatment of syphilis. Fracastoro also coins the term *syphilis*, which is the name of a mythical youth who develops the disease in his work. *See also* 1495 MED; 1546 MED.

Paracelsus's *Paragranum* argues that medicine should be based on nature and its physical laws and is the first to suggest the use of chemical substances, such as compounds of mercury and antimony, as remedies. *See also* 1527 FOOD.

The first book on dentistry is published in Leipzig (Germany).

✳ Tools

The spinning wheel is in general use in Europe. Johann Jürgen improves on it by adding twisting rotation to the thread. *See also* 1520 TOOL; 1738 TOOL.

1533

✳ Food & agriculture

Catherine de Medici marries the future King Henry II of France and brings forks, meals with separate courses, and

serious cuisine from Italy into France for the first time.

French cuisine as we know it today will grow from this Italian beginning. *See also* 1370 FOOD; 1611 FOOD.

Σ Mathematics

Mathematician and geographer Reiner Gemma Frisius [b. Dokkum, Friesland (Netherlands), December 8, 1508, d. Louvain (Belgium), May 25, 1555] describes the method of separating a region into a series of triangular elements based on a line of known length so that accurate surveying can be accomplished with the aid of trigonometry. Surveyors call this method triangulation. *See also* 1513 TOOL.

↗ Transportation

Reiner Gemma Frisius is the first to point out in *De principiis astronomiae et cosmographie* ("principles of astronomy and cosmology") that knowing the correct time according to a mechanical clock and comparing it with Sun time can be used to find the longitude. *See also* 1598 TRAN; 1659 TRAN.

1535

Σ Mathematics

Niccolò Tartaglia announces that he can solve certain types of cubic equations, types that were not previously solved by Scipione del Ferro. *See also* 1075 MATH; 1541 MATH.

♥ Medicine & health

Dispensatorium by Valerius Cordus [b. Hesse (Germany), February 18, 1515, d. Rome, September 25, 1544], one of the first books to describe most known drugs, chemicals, and medical preparations, is published.

Old and New World plants meet

The region around the North Pole is called by biologists the Holarctic. This ecosystem was integrated in many ways long before any people populated the New World. Forests of pine or oak filled with brown bears dining on bramble berries and salmon, and tundra tramped by reindeer (caribou) hunted by wolves, were and are typical of both northern North America and northern Eurasia. When people arrived in those northern regions — whether proto-Indians from Asia or post-Columbus explorers from Europe — there was little to surprise them.

South of the Holarctic region, however, Old and New World species diverge. The most dramatic example is the marsupial order of mammals, found in southern North America and all of South America, but totally lacking in Eurasia. Old and New World insects, plants, and other life forms often bear only a distant relationship, making the division into two "worlds" sensible. A few odd relationships do exist, however. Many plants, for example, are native both to North America and China in closely related forms.

Technology in the Old and New Worlds was directly affected by this divergence of plants and animals. One reason often advanced for the lack of development of wheeled vehicles in the Americas is that there was no suitable native fauna that could be converted into draft animals. Conversely, Native Americans found a vast range of suitable flora for domestication. Although Old World rice and wheat dominate the carbohydrate basis of the human diet in most of the world, it is difficult to imagine any complex cuisine not based on such New World plants as chili peppers (hot or sweet), tomatoes, potatoes, green and dried beans, pecans, cashews, peanuts, and squash. Furthermore, large populations of humans depend on New World corn and manioc as their main carbohydrate; and corn is the basis of the food pyramid for farm animals around the world. Not to mention avocados and chocolate. Where civilization started, in the Near East, the native plants that became important include wheat, rye, barley, oats, cucumbers, figs, peas, lentils, olives, walnuts, dates, apricots, pears, and grapes. From Europe we have garlic, onions, beets, the cabbage family, lettuce, cherries, apples, carrots, parsley, and the minty herbs. Other plants were domesticated in Asia, including rice, and New Guinea — bananas and taro.

Oddly, there is one plant that was domesticated in both the Old and New worlds — cotton. Perhaps its mobile seeds were a factor, although some archaeologists suspect that somehow cotton was transferred by humans in very early pre-Columbian contact. Cotton does get around. One wild variety is found in Hawaii.

The vast interchange of plants that took place, largely in the 16th century and continuing on to today, has remade the landscape of the world. It is difficult to imagine California without chaparral or eucalyptus, Kansas without wheat, Australia without sheep, or North American roadsides without blue chicory, Queen Anne's Lace, Russian thistle, purple loosestrife, and many other European escapees.

Sometimes New World plants provided a whole technology that had been completely lacking in the Old. No one in Europe had even considered a substance like rubber, which was first encountered by Europeans on Columbus's second voyage, in 1495. Native Americans knew that rubber could be used to make balls that bounced, but they had little other use for the substance. After 175 years of European knowledge of rubber, a second use was found — it could erase marks made by India ink or by a graphite pencil. Fifty years or so later, a Scotsman found a way to make raincoats from it. Twenty years after that the first rubber tires, still far from their ultimate popularity, were installed on wheels. By the 20th century, rubber had become such a necessity that when wartime cut off supplies, vast sums were spent seeking synthetic versions of it.

The great plant interchange had significance for science as well. About the same time as the new plants began to reach Europe, so did a rediscovery of the works of the first great botanist, Theophrastus. His work had been stimulated in part by the Greek discovery of Indian flora in the conquests of Alexander. This rediscovery, along with the arrival of thousands of plants from the New World, contributed to the development of botany in the works of Leonard Fuchs, Konrad von Gesner, Charles Lécluse (Clusius), Caspar Bauhin, John Ray, and, ultimately, Linnaeus. The New World flora continued to have an impact well into the 19th century, forming one of the main influences on the ideas of Charles Darwin and those of Alfred Wallace, who had traveled to the Amazon basin and written about South American plants before his sojourn in the East Indies.

→ Transportation

Italians use glass diving bell to explore sunken ships in Lake Nemi. *See also* 50 CE TOOL; 1620 TRAN.

1536

Σ Mathematics

Hudalrichus Regius's *Utriusque arithmetices* includes the fifth known perfect number, 33,550,336. A

perfect number is one that is the sum of its proper divisors, including 1, such as 6 which is $1 + 2 + 3$; then comes the second, 28; the third, 496; and the fourth, 8128. *See also* 1603 MATH.

→ Transportation

The earliest known book on shipbuilding, *De re navalı* ("of naval things") by Lazarus Bayfius, is published. *See also* 1595 TRAN.

1537

❖ Physics

Niccoló Tartaglia writes *Della nova scientia* ("of the new science"), initiating the science of ballistics, in which he shows that the ball from a cannon will travel the maximum distance when fired at an angle of 45°. *See also* 1420 TOOL.

1538

★ Astronomy

Girolamo Fracastoro's *Homo-centrica* introduces a model of the planetary system close to Eudoxus's model, containing 79 spheres. *See also* 380 BCE AST.

1539

❖ Food & agriculture

Alonso Herrera publishes his *Libro di agricultura*.

Jerome Bock a.k.a. Hieronymus Tragus [b. Heidesbach (Germany), 1498, d. Hornbach (Germany), February 21, 1554] writes *Kräuterbuch* ("book on herbs") describing plants that grow in Germany. The herbal contains the first attempt at natural classification of plants, using similarity of form and dividing plants into herbs, shrubs, and trees. An illustrated edition will be published in 1546. *See also* 1530 BIO; 1542 FOOD.

Hernando de Soto [a.k.a. Fernando, b. Jerez de los Caballeros, Spain, d. banks of Mississippi River (United States), June 20, 1542], lands at Tampa (Florida) and introduces the pig into North America.

1540

★ Astronomy

Astronomicon caesareum by Peter Apian notes that comets always have their tails pointing away from the Sun, a fact known to the Chinese for more than 900 years, but not known in Europe before this. *See also* 635 AST; 1617 AST.

De le stelle fisse ("on fixed stars") by Alessandro Piccolomini [b. Siena, Italy, June 13, 1508, d. Siena, March 12, 1578] is the first star atlas in which stars are labeled with letters.

Narratio prima de libris revolutionum ("first explanation of the book on revolutions") by German mathematician Georg Joachim Rheticus (Georg Joachim von Lauchen) [b. Feldkirch, Austria, February 16, 1514, d. Cassovia, Hungary, December 4, 1576] summarizes the heliocentric planetary model that Copernicus has developed but not published. *See also* 1514 AST; 1543 AST.

❖ Construction

The Pont Neuf at Toulouse, France, is an early example of a bridge constructed with semi-elliptical arches instead of semicircular ones. *See also* 1345 CONS; 1569 CONS.

❖ Materials

Christoph Schurer uses cobalt in the production of blue glass.

Northern Italian mine superintendent Vannoccio Biringuccio publishes *De la pirotecnica* ("on working with fire"), a book giving practical information on the treatment of ores, smelting of metals, distillation, and sublimation.

It also describes a boring machine for cannon that is powered by pedals. *See also* 1774 TOOL.

I Tools

The first matchlock musket is made. The gun requires two persons to hold and fire it, igniting the charge with an improved form of the matchlock developed earlier. *See also* 1500 TOOL.

The Portuguese mathematician and cosmographer Pedro Nunes Salaciense, a.k.a. Pedro Nuñez [b. Alcácer do Sol, Portugal, 1502, d. Coimbra, Portugal, August 11, 1578] invents the scale named after him (the nonius). It consists of a series of fixed scales mounted concentrically on an astrolabe. The gradations on each scale are somewhat shifted so that the fractional part of a curve indicates the fractional part of a degree. *See also* 1631 TOOL.

1541

Σ Mathematics

Niccoló Tartaglia and Antonio Maria Fiore engage in a famous contest in mathematics. Challenged to solve each other's set of cubic equations, Tartaglia solves all of Fiore's, while Fiore fails to solve even one of Tartaglia's. Tartaglia has previously solved the general cubic (polynomial equation of the third degree), making it easy for him to win. His solution is published by Jerome Cardan in 1545. *See also* 1535 MATH; 1545 MATH.

1542

❖ Food & agriculture

Leonhard Fuchs [b. Bavaria

(Germany), January 17, 1501, d. Tübingen (Germany), May 10, 1566], for whom the shrub fuchsia and color of its blossoms is named, describes about 400 German and 100 foreign plants, including peppers, pumpkins, and maize from the New World. *See also* 1539 BIO; 1560 FOOD.

Σ Mathematics

The Grounde of Artes by Robert Recorde [b. Tenby, Wales, 1510, d. London, 1558] is a popular arithmetic textbook that runs through 29 editions. *See also* 1478 MATH.

♥ Medicine & health

A book on anatomy by Jean François Fernel [b. Montdidier, Somme, France, 1497, d. Fontainbleau, France, April 26, 1558] is the first to describe appendicitis and peristalsis (the waves of contraction in the digestive system that move food through the alimentary canal).

I Tools

Ralph Hog of Buxted, Sussex, England, is the traditional inventor of cast-iron cannon in the West, although Chinese cannon had been made from cast iron for hundreds of years by this time. *See also* 1378 TOOL; 1739 TOOL.

1543

★ Astronomy

Copernicus's *De revolutionibus orbium caelestium* ("on the revolutions of celestial bodies") is a convincing recasting of planetary motions based on the assumption that Earth and other planets revolve around the Sun. *See also* 140 CE AST; 1551 AST.

The pepper plant's story

Columbus, from his first voyage onward, met Native Americans who were farmers. Columbus was looking for gold and spices; although he did not find much in the way of gold, he believed he had discovered spices, for he thought that a Caribbean shrub was cinnamon and that other plants were those reported from the East by Marco Polo. It is not clear whether he thought the *Capsicum* of the New World — the common green or red pepper — to be the same as black pepper; he clearly refers to "very hot spices" that must have been *Capsicum*. By 1493, Matyr (Pietro Martire de Anghiera) was using the accounts of Columbus's first voyage to describe *Capsicum*, which he called peppers, although clearly differentiating the American peppers from black pepper.

Although archaeological remains in the Americas make it clear that *Capsicum* originated there, there are puzzling aspects to how it traveled from the Americas, which it did quite speedily. The padres that accompanied the Spanish explorers brought back seeds of many plants, including *Capsicum*, for their monastery gardens. After that, the pattern of distribution becomes unclear.

For example, most botanists before 1600 thought that *Capsicum* had been imported from India, not the Americas. There was a reason for this belief. There is good evidence that *Capsicum* first reached Germany before 1542 from India, not the Americas. Thus, in less than 50 years, *Capsicum* had circled three-

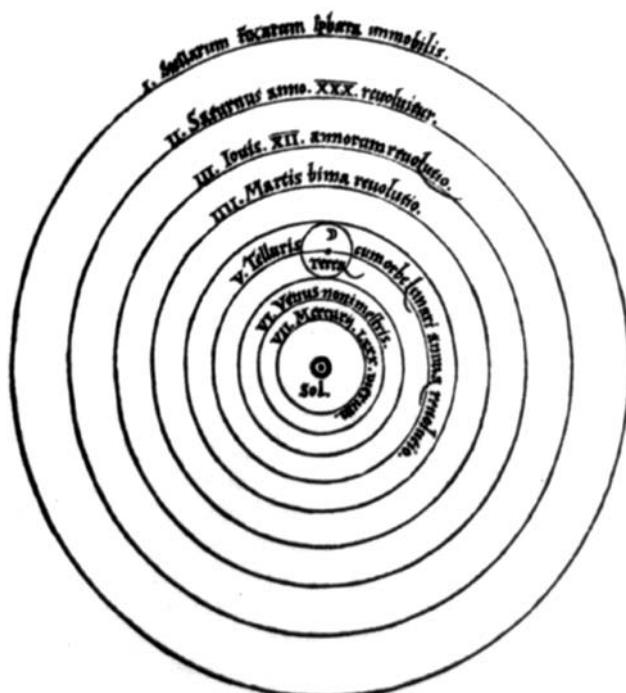
quarters of the way around the globe, traveling in what would seem to be the wrong direction.

The conventional view is that Portuguese sailors took *Capsicum* to their colonies in India sometime between their first voyages in 1498 and 1513. There, peppers could have been introduced to the Indians, as well as to the Ottoman Turks, who besieged the Portuguese colonies in 1513 and 1538. Then the Turks could have carried peppers with them to the Balkan peninsula, which they occupied. Botanists in Europe then would have gotten them from the Turks, who said the peppers were Indian. The tale becomes somewhat complicated because early writers attributed the origin of the name *Capsicum* to a 13th-century botanist, who, of course, wrote before Columbus's voyage.

The Indian connection remains somewhat of a mystery, especially because *Capsicum* is so much a part of Indian food. It should be noted, also, that traditional cooking from some regions of China is heavily dependent on *Capsicum*.

A further mystery is that *Capsicum* was being cultivated in Melanesia when the first Europeans arrived. Theories that explain this involve native traders bringing the plants by stages from India.

Of course, *Capsicum* quickly settled into Europe, becoming an essential part of the cuisine of Italy, for example, and Hungary (in the form of paprika). Other American food plants also quickly became naturalized, including the tomato, the potato, and the American bean. As a result, it is difficult to imagine any European cuisine before 1500.



COPERNICAN VIEW OF THE UNIVERSE The planets out to Saturn are shown in their correct order orbiting the Sun and the Moon revolves about Earth.

Notice that the outer circle, representing the stars, is marked *immobilis* ("stationary") while the planets and Moon are marked *revolutio* ("rolling").

Biology

Luca Ghini finds the first European botanical garden in Pisa (Italy). *See also* 1274 FOOD; 1545 BIO.

Medicine & health

De humani corporis fabrica ("on the structure of the human body") by Flemish anatomist Andreas Vesalius is the first truly accurate work on human anatomy. Vesalius describes the anatomy of the brain, with the first illustrations of the corpus callosum, thalamus, and other parts.



Andreas Vesalius

[b. Brussels (Belgium), December 31, 1514, d. Zante, Greece, October 15, 1564]

Considered the father of modern anatomy, Vesalius made careful dissections of human cadavers. In 1543 he published *On the Structure of the Human Body*, a seven-volume text that contained the first accurate illustrations of internal human anatomy. His rejection of many of the teachings of the ancient Greek physician Galen was controversial, forcing him to leave teaching — but this led to an appointment as physician to Holy Roman Emperor Charles V.

Physics

French philosopher and mathematician Peter Ramus (Pierre de Rame) [b. Vermilion, France, 1515, d. August 26, 1572], during the St.

Bartholomew massacre in

Paris] attacks Aristotelian physics in his *Aristotelicae antimadversiones* ("reproof of Aristotle"). *See also* 1328 PHY.

Tools

The Japanese obtain their first guns from Chinese sources.

1543: A great year in publishing

The year 1543 was marked by the publication of two books that revolutionized our view of humanity and the universe.

The more celebrated of the two, Nicolaus Copernicus's *De revolutionibus orbium caelestium* ("on the revolutions of celestial bodies"), was actually completed in the 1530s, but Copernicus was reluctant to publish for fear of reprisals from the church. His work circulated among intellectuals as Russian *samizdat* manuscripts were passed about in the former Soviet Union in the 20th century. In his book Copernicus offered arguments that Earth and other planets travel around the Sun; however, his assumption of circular motion meant that he had to complicate the paths by adding 48 epicycles to them to accord with observation. Copernicus said that the stars do not appear to move as Earth moves in an orbit because the fixed stars are so far away, although he vastly underestimated how far away they actually are.

As Copernicus neared death, he was finally persuaded to publish by the mathematician Rheticus. The actual publication was overseen by a Lutheran minister, Andreas Osiander, who — presumably concerned because Luther did not believe Earth moves — added a preface that said, in effect, Earth does not move but calculations would be easier if one assumes it does. A few hundred copies were printed a month or so before Copernicus's death; it is not clear whether he saw the published version.

From a publisher's point of view, the book was not a success. It was very high-priced and sold slowly. It went out of print, although a second edition was published in 1566 and a third in

1617. But most astronomers came to believe that Copernicus was right, notably Galileo, who spread the word more widely. The last great astronomer to hold a different view was Tycho Brahe, who died in 1601 still believing that Earth does not move; however, he did think that the other planets revolve about the Sun.

The other book from 1543 that changed the world was *De humani corporis fabrica* ("on the structure of the human body") by Andreas Vesalius. Unlike Copernicus, Vesalius decided to publish when he was a young man, not quite 30. However, Copernicus might have had the right idea about keeping new ideas quiet. After Vesalius published his book, accusations of body snatching and heresy were directed against him by physicians loyal to older ideas. Whether because of this or for other reasons, Vesalius spent the rest of his life as a court physician, doing almost no more research.

De humani corporis fabrica is most important because it is a printed book with exceptional illustrations (usually attributed to the painter Stephen van Calcar). For the first time, the true anatomy of the human body as perceived by a great anatomist was reproduced in many accurate copies. Previous books on the subject generally lacked illustrations or had a few copied by hand, a method sure to introduce inaccuracies.

Before Vesalius, physicians were taught from Galen, even when Galen's authority did not conform to what was observed. Although Vesalius had been educated in this tradition, he rejected it when confronted with the evidence of his own dissections. Although physicians still loyal to Galen denounced the book, later anatomists, like the astronomers after Copernicus, sought the truth instead of authority.

Gunpowder and guns in East and West

When gunpowder was invented by the Chinese, they were afraid of it, which was natural; but they did not immediately think of guns, which seems odd to people in the West to this day. It took nearly 500 years for word of gunpowder to reach Europe, but almost no time after that for Europeans to invent guns. The Chinese, and others in the East who learned of gunpowder from the Chinese, did use the explosive mixture in war, but at first they counted on its loud noise scaring the enemy. Later they developed bombs or grenades as well as military rockets. But none of these devices was to have the effect on world order that guns very quickly came to have.

An interesting example of the different reaction to guns and gunpowder comes from Japan. Like other Eastern peoples, the Japanese learned of gunpowder bombs and rockets from the Chinese, Mongols, and Koreans in the course of various wars. But on August 25, 1543, the Japanese found out about guns for the first time when a Chinese junk with three Portuguese aboard drifted ashore. The Portuguese had guns — match-fired muskets known as arquebuses. Within a year the guns had been copied and manufactured all over Japan, which was then in a period of intense internal wars. According to one account, by

1556 there were 300,000 arquebuses in Japan and wars were being won by arquebus-armed soldiers against cavalry armed with swords. Cannon were also introduced late in the 16th century and became important in the many local wars.

But early in the 17th century, the local wars were over and the period of stability known as the shogunate had started. Although guns were not banned (as sometimes has been written), they were no longer viewed as necessary. Swordsmanship was what was important to the samurai warriors. This period, when swords replaced guns for more than 200 years, inspired many science-fiction adventure novels, in which a culture spurns its many powerful weapons and fights with swords or with primitive guns.

The Western guns were among the many factors that helped ensure dominance of Europe over Africa, the Americas, Asia, and Oceania, although other elements were also important in each case. Indeed, Spanish hand weapons in Mexico were not powerful enough to penetrate cotton armor on native armies (but cannon and disease germs were effective enough). In Asia, the Japanese abandonment of gun power left the island powerless to resist heavily armed Western battleships early in the 19th century, but by the end of the century they had remedied that situation and were able early in the 20th century to defeat Russia, both on land and sea in the Russo-Japanese War.

1544

Communication

Cosmographia, published in Germany by Sebastian Münster [b. January 20, 1488, d. May 26, 1550], is the first major compendium on world geography. *See also* 1406 COMM.

Earth science

Engineer and physicist Georg Hartmann [b. Eckolsheim (Germany), February 9, 1489, d. Nuremburg (Germany), April 8, 1564] observes magnetic dip (the magnetic needle, while pointing north, is not entirely horizontal). *See also* 1530 EAR; 1581 EAR.

Mathematics

Arithmetica integra by German mathematician and theologian Michael Stifel [b.

Esslingen (Germany), 1487, d. Jena (Germany), April 19, 1567] summarizes the knowledge of algebra and arithmetic known to date.

Tools

The French Royal Ordnance introduces six calibers that all artillery must use, thus standardizing the production of ammunition. *See also* 1436 TRAN.

1545

Mathematics

Ars magna ("great art") by Girolamo Cardano (better known in English as Jerome Cardan) [b. Pavia (Italy), September 24, 1501, d. Rome, September 21, 1576] is the first book of modern mathematics, containing not only Cardano's stolen and pur-

chased solutions to the cubic and quartic, but also the first acceptance of negative numbers and even a passing nod at complex numbers. *See also* 1484 MATH.

Medicine & health

A book on surgery by Ambroise Paré [b. Mayenne, France, 1510, d. Paris, December 20 1590] advocates abandoning the practice of treating wounds with boiling oil and using soothing ointments instead. *See also* 1500 MED; 1655 MED.

Physics

In lectures at the University of Salamanca, published this year, Spanish Dominican theologian and political philosopher Domingo de Soto [b. Sequoia, Spain, 1494, d. 1560] is the first to recognize that an object accelerates during free

fall, a discovery often attributed to Galileo nearly 100 years later. De Soto also derives the laws of free fall using a geometric proof. *See also* 1604 PHY.

1546

Construction

Pope Paul III asks Michelangelo to correct the errors in Bramante's 1503 design for St. Peter's Church in Rome and to complete the construction of the edifice. *See also* 1590 CONS.

Earth science

De natura fossilium ("about the nature of things found by digging") by German metallurgist Georgius Agricola introduces the word *fossil* for anything dug from the ground, including what Agri-

cola believed were odd rocks that looked like bones or shells. He also offers a correct explanation of the origin of some minerals as precipitates from water in *De ortu et causis subterraneis* ("on subterranean origin and causes"). *See also* 1565 EAR.

II Food & agriculture

Luigi Alamanni [b. Florence (Italy), 1495, d. Amboise, France, April 18, 1556] publishes *La coltivatione* ("cultivation"), a book of poems in imitation of Virgil's *Georgics* that contains advice to farmers and arborists.

Σ Mathematics

Mathematician and cartographer Pedro Nunes Salaciense writes *Navigandi libri duo*, a guide to navigation. *See also* 1540 TOOL.

♥ Medicine & health

Girolamo Fracastoro's *De contagione* ("on contagion") advances the idea that diseases

Georgius Agricola (Georg Bauer)

[b. Glauchau, Saxony, March 24, 1494, d. Chemnitz, Saxony, November 21, 1555]

Although best known by the Latinized form of his name, Agricola was born Georg Bauer. Both *Bauer* and *agricola* mean "farmer," but Agricola was a physician who specialized in diseases of miners in the main mining centers of Saxony. His principal contribution to science is his posthumously published (1556) book *De re metallica* ("on metallic matters"), a clear, well-illustrated summary of what German miners had learned and how they operated. His earlier writings on minerals and geology are also valuable resources.

are seedlike entities that are transferred from person to person. *See also* 1530 MED.

1548

Chemistry

Gioaventura Rosetti publishes in Venice (Italy) a treatise on dyeing.

1550

★ Astronomy

Girolamo Cardano uses the measurement of parallax to establish that comets are not atmospheric phenomena — although credit for this is usually given to Tycho Brahe a quarter of a century later.

Parallax is the observed change in position of an object caused by a change in position of the viewer. If one can measure the angle between the two lines of sight, simple trigonometry enables one to find the distance from the observer to the object. *See also* 1577 AST.

↳ Communication

Prince Thurn und Taxis (Germany) receives the authorization of Charles V to forward private messages, thus starting the first postal service open to the general public. *See also* 1464 COMM; 1840 COMM.

Girolamo Cardano describes in *De subtilitate libri XXI* a camera lens for use with the

camera obscura. *See also* 1020 COMM; 1553 COMM.

❖ Materials

Spanish conquistadores and colonists recognize large deposits of platinum, but are more annoyed than pleased. Although the metal is unknown in Europe, the Spanish view it largely as a potential source of counterfeit gold because of its high density. *See also* 1000 MATR.

Venetian glassmakers develop techniques for making mirrors from glass backed with reflecting metals, such as tin or mercury amalgam. *See also* 2500 BCE MATR; 1840 MATR.

A great scoundrel

In the Italian Renaissance, the professions of scientist and mathematician were just beginning to be defined. One such scholar was Girolamo Cardano, known in English as Jerome Cardan. Cardan's basic source of income was his work as a physician, but he was also at various times a professor of mathematics at the universities of Milan, Pavia, and Bologna. Other sources of income included gambling and astrology; however, he was imprisoned for heresy after he cast Christ's horoscope.

Cardan's reputation as a mathematician is deservedly great, but marred by scandal. His 1545 work *Ars magna* ("great art") contains the first printed methods for solving all algebraic equations whose highest exponent is three (cubics) and all equations whose highest exponent is four (quartics).

At the end of the 15th century, European mathematicians believed that the cubic would never be solved. But Scipione del Ferro partially solved the cubic early in the 16th century, keeping

his solution to himself. Before his death, however, del Ferro passed along his secret method to his pupil, Antonio Maria Fiore. Meanwhile, a self-taught mathematical genius known to posterity as Tartaglia ("the stutterer") discovered how to solve many kinds of cubics. He used his secret methods to best Fiore in a mathematical duel, solving all the problems Fiore posed while Fiore solved none of Tartaglia's.

Cardan somehow persuaded Tartaglia to reveal his secret; in return, Cardan promised to keep the secret so Tartaglia could publish it later. Instead, however, Cardan put Tartaglia's secret method into his own book, *Ars magna*. He did, however, credit Tartaglia with the original work. Cardan also expanded on Tartaglia's work to cover all forms of the cubic.

Ars magna also contains the method for solving the quartic, the next higher degree equation. But once again Cardan did not work out the solution on his own. Instead he got it from a pupil, Luigi Ferrari, "who invented it at my request."

♥ Medicine & health

Tobacco is being cultivated in Spain. *See also* 1507 MED; 1586 MED.

I Tools

Rolling mills are in use at Nuremberg (Germany). *See also* 1496 TOOL; 1700 TOOL.

1551

★ Astronomy

German astronomer and mathematician Erasmus Reinhold [b. Thuringia (Germany), October 22, 1511, d. Thuringia, February 19, 1553] publishes astronomical tables based on Copernicus's theory. These tables are the first improvement over the Alfonsine Tables of 1252.

❀ Biology

The first volume of *Historia animalium* by Konrad von Gesner [b. Zürich, Switzerland, March 26, 1516, d. Zürich, December 13, 1565] is the beginning of the science of zoology; three more volumes are published through 1558. This is a heavily illustrated work that describes animals, including their habits and instincts. *See also* 1555 BIO.

Σ Mathematics

Robert Recorde's *The Pathwey of Knowledge* is a popular abridgment of the *Elements of Euclid*.

I Tools

Leonard Digges [b. Canterbury, Kent, England, c. 1520, d. c. 1559] invents the theodolite, the telescope used in surveying to measure horizontal and vertical angles. The invention is published by his mathematician son Thomas [b.

Kent, 1546, d. London, August 24, 1595] in 1571.

1552

❀ Food & agriculture

The *Badianus Manuscript* is compiled by two Aztec scholars with a text in Nahuatl (the Aztec language) by Martinus de la Cruz and a Latin translation by Juannes Badianus. The catalog of medicinal plants from Central America with color illustrations is available only in the Vatican library until 1940, when the first facsimile edition is published. *See also* 1671 FOOD.

1553

⌚ Communication

Giovanni Battista Bellaso [b. Brescia (Italy), 1501, d. c. 1565] publishes *La cifra del Sig. Giovanni Battista Bellaso* ("the cipher of Mr. John Battista Bellaso"), in which he describes the use of codes and ciphers.

According to tradition, Italian physicist Giovanni Battista della Porta [b. near Naples, October 1535, d. Naples, February 4, 1615] invents the camera obscura — although there are clear references to the device by Alhazen, Roger Bacon, Leonardo da Vinci, Girolamo Cardano, and others, all preceding della Porta. *See also* 1550 COMM.

❀ Food & agriculture

Spanish explorer Pedro de Cieza de León [b. c. 1518, d. 1560] describes the potato in *Chronicle of Peru*. *See also* 1565 FOOD.

♥ Medicine & health

An anonymously published

book on theology, written by physician Michael Servetus (Miguel Serveto) [b. Villanueva de Sixena, Spain, September 29, 1511, d. Geneva, Switzerland, October 27, 1553] contains his view, soon to be demonstrated by Realdo Colombo, that blood circulates from the heart to the lungs and back. His authorship discovered, his unorthodox theological views result in Servetus being burnt at the stake on October 27 in Geneva by John Calvin. *See also* 1559 MED.

1555

❀ Biology

Naturalist Pierre Belon [b. Soultière, France, 1517, d. Paris, April 1564], who is the first to notice homologies between specific bones in vertebrates from fish to mammals, writes *L'histoire de la nature des oyseaux* ("history of the nature of birds"). It contains a classification of 200 species and compares bone anatomy of birds and humans. *See also* 1551 BIO; 1693 BIO.

1556

⌚ Communication

The Portuguese print *Concluções publicas et Doctrina Christiano* in India. It is the first book printed in that country.

❀ Earth science

Late in January or early in February, an earthquake strikes Shensi Province in China, killing perhaps 830,000 people — the worst earthquake disaster in history.

❀ Food & agriculture

Count Van Egmond begins drainage of the Egmondermeer, the start of much larger drainage operations in the Low Countries than any previously. *See also* 1514 FOOD.

❖ Materials

De re metallica ("on metallic matters") by Georgius Agricola, published posthumously, offers a detailed discussion of where mineral veins are found. The book remains an important reference until the end of the 18th century. *See also* 1505 MATR; 1574 MATR.

1557

Σ Mathematics

Robert Recorde's *The Whetstone of Witte* introduces an elongated version of the equal sign, =, into mathematics (asking what could be more equal than a pair of parallel lines); it also introduces the + and – signs for addition and subtraction into English. *See also* 1514 MATH; 1631 MATH.

❀ Physics

Italian physician Julius Caesar Scaliger [b. Riva (Italy), 1484, d. Agen, France, October 21, 1558] makes what seems to be the first written reference to platinum, which had been discovered a few years earlier. *See also* 1550 MATR.

1559

⌚ Communication

The papal authorities publish the *Index librorum prohibitorum*, commonly known as the Index. The Index is a list, regularly updated, of books forbidden to be read by Catholics except with special authorization.

1559–1560

tion from the church. *See also* 1485 COMM.

♥ Medicine & health

Italian anatomist Realdo Colombo, a.k.a. Mateo Realdo Colombo [b. Cremona (Italy), c. 1516, d. Rome, 1559], although a supporter of Galen against the new anatomy of Vesalius, in *De re anatomica libri XV*, published this year, claims that blood circulates from the right chamber of the heart to the lungs and then to the left chamber. This view contradicts Galen, who thought the blood passes directly between the two chambers. *See also* 1553 MED; 1616 MED.

1560

↳ Communication

Architect Giacomo della Porta [b. Porlizza (Italy), c. 1533, d. 1602] founds the Academia Secretorum Natura, the first scientific society. The society is suppressed by the Inquisition, but replaced by the Accademia dei Lincei in 1603. *See also* 1575 COMM; 1603 COMM.

¶ Construction

Saint Basil's Cathedral is completed outside of the Kremlin in Moscow. It has eight separate chapels clustered around a central altar, each capped with colorful onion domes of different heights. The cathedral is at one edge of Red Square. According to legend, Ivan the Terrible blinds the builders when the cathedral is completed so that they cannot build another so beautiful.

Military engineer Adam de Craponne [b. 1527, d. 1576] builds the 65-km (40-mi)



ST. BASIL'S CATHEDRAL ON RED SQUARE Although dramatic onion-dome cathedrals can be found throughout Russia, none matches the exuberance of St. Basil's.

Canal de Craponne for irrigation (also used as a power source by some mills) in the south of France, the earliest French canal. *See also* 1458 TRAN; 1642 TRAN.

1561

♥ Medicine & health

Observationes anatomicae ("anatomical observations") by Italian anatomist Gabriel Fallopius [b. Modena (Italy), c. 1523, d. Padua (Italy), October 9, 1562] describes the organs of the inner ear and the female reproductive system, including the fallopian

tubes that are named for him. *See also* 1543 MED; 1563 MED.

1563

♥ Medicine & health

Italian anatomist Bartolomeo Eustachio [b. San Severino (Italy), c. 1510, d. Urbino (Italy), August 27, 1574] describes the adrenal glands, the detailed structure of the teeth, and the eustachian tubes, named after him. His work is not published until 1714, however. *See also* 1561 MED; 1573 MED.

1564

↗ Transportation

The horse-drawn coach is introduced from Holland to England. *See also* 1457 TRAN.

1565

;element Chemistry

It is known that silver salts turn black, but the association of this change with light is not yet recognized. *See also* 1727 CHEM.

⌚ Communication

Philosopher and scientist Bernardino Telesio [b. Cosenza, Calabria (Italy), 1509, d. Cosenza, 1588] urges the importance of knowledge based on experiment in *De rerum natura juxta propria principia* ("on the nature of things according to their proper principles"). *See also* 1605 COMM.

¶ Construction

Following the design of an Italian engineer, the Spanish settlement of Saint Augustine in Florida — the first European town in what will become the United States — is a heavily armed fortress developed to withstand a long siege. It is similar to those common at this time in Europe. *See also* 1599 CONS.

⊕ Earth science

Konrad von Gesner's *De omni rerum fossilium* ("on all things dug up from the earth") contains the first drawings of fossils, although Gesner believes them to be rocks that just happen to look like bones or shells. *See also* 1546 EAR.

🍴 Food & agriculture

The first potatoes arrive in Spain from America. *See also* 1553 FOOD.

❖ Materials

Konrad von Gesner describes the pencil, which may have been invented near the beginning of the 16th century. Although the “lead” in the pencil Gesner mentions probably is graphite (a major strike of excellent graphite has just occurred in England), he says that the pencil is formed of wood and “English antimony.” *See also* 1492 MATR.

1566

🍴 Food & agriculture

Camillo Torello patents the first seed drill known in Europe, nearly 1700 years after its invention in China c. 85 BCE.

1568

⌚ Communication

The first industrial exposition is held at Nuremberg (Germany).

Flemish geographer Gerardus Mercator (Gerhard Kremer) [b. Rupelmonde (Belgium), March 5, 1512, d. Duisburg (Germany), December 2, 1594] introduces the map projection that bears his name. *See also* 940 AST; 1595 COMM.

1569

🌿 Biology

Sunflowers are imported into Spain from America. *See also* 4000 BCE FOOD.

🏗 Construction

Bartolomeo Ammanati [b. Settignandi (Italy), 1511, d. Firenze (Florence, Italy) 1592] builds the “basket-handle” or elliptical-arch bridge known as the Ponte Santa Trinita or Ponte della Trinita over the Arno just below the Ponte Vecchico at Florence. *See also* 1345 CONS; 1591 CONS.

I Tools

Jacques Besson [b. Colombières, France, c. 1530, d. Orléans, France, 1573] publishes his *Theatrum instrumentorum et machinarum* (“theater of instruments and machines”), based largely on the work of Francesco di Giorgio, which pictures a large number of mechanisms and mechanical devices with short captions. Of most importance, he describes and illustrates a lathe he has designed for woodworking and what may be the first workable screw-cutting machine. *See also* 1578 TOOL.

1570

⌚ Communication

A loose collection of maps called *Theatrum orbis terrum* is produced by Abraham Ortelius [b. Antwerp (Belgium), April 14, 1527, d. Antwerp, July 5, 1598]; it is the first atlas to be published. *See also* 1513 COMM; 1595 COMM.

🏗 Construction

Architect Andrea Palladio [b. Padua (Italy), November 30, 1508, d. Maser (Italy), August 19, 1580], perhaps the first architect to understand fully how the truss works (although it was used extensively in the

Middle Ages), publishes *I quattro libri dell'architettura* (“the four books of architecture”) in Venice. *See also* 126 CE CONS; 1792 CONS.

✈ Transportation

A Dutch sailor introduces the first separate topmast, an extension of the mainmast that can be added or removed as weather conditions change. The topmast also has the advantage of permitting the use of shorter spar trees to make the mainmast. *See also* 1400 TRAN.

1572

★ Astronomy

Tycho Brahe observes a new star (which he calls a *nova*, but which we now would call a *supernova*) in Cassiopeia, destroying the Aristotelian concept of the immutability of the heavens. The star is also recorded by Chinese astronomers. As bright as Venus, it remains visible for 15 months. *See also* 1006 AST.

Σ Mathematics

The *Algebra* of Rafael Bombelli [b. Bologna (Italy), January 1526, d. 1572] shows the first application of complex numbers to solve equations, including equations with real solutions. Bombelli also uses continued fractions (fractions with an infinite sequence of fractional denominators) to approximate roots. *See also* 1613 MATH.

1573

★ Astronomy

Tycho Brahe publishes *De nova stella* (“on the new star”), giving an exact description of his observation of the supernova of 1572. *See also* 1572 AST.

♥ Medicine & health

Costanzo Varolio [b. (Italy), 1543, d. 1575] describes the cranial nerves and the pons. *See also* 1543 MED; 1586 MED.

✈ Transportation

By this date Humphry Cole supposedly invents the ship’s log for keeping track of the speed of a ship with respect to the water. The first printed reference, from this year, is to the log-and-line, in which a float attached to a line is paid out for a specified time and the length of the line is used to measure the speed. *See also* 1577 TRAN.

1574

★ Astronomy

Tycho Brahe’s *Oratio de disciplinis mathematicis* presents an organic view of the universe, comparing the parts of the universe to human organs.

The immutability of the heavens

The Greek concept of the universe was detailed by Aristotle. This Greek cosmology included the idea that something had to hold up the stars and planets, something that could not be seen. Since the only hard substance known that was also transparent was crystal (transparent calcite), Greek logic insisted that spheres of crystal hold the stars, Sun, Moon, and planets in place.

Greek tradition also included the idea that the heavens are very different from Earth. On Earth, everything is changing all the time. In the heavens, nothing ever changes, they believed. Comets, however, appear in the heavens, last a few days or weeks, and disappear. This constitutes change. Therefore, Aristotle argued, comets are earthly stuff, not heavenly stuff, and must be some kind of spontaneous fire in the upper atmosphere. Then the comet of 1577 showed that Aristotle could not be right about the heavens.

Tycho Brahe, Michael Mästlin, and other astronomers were able to plot the comet's path. Tycho Brahe also used parallax in an effort to determine the distance of the comet of 1577 from Earth. Parallax refers to the apparent angular difference in position of an object when seen from two locations. The amount of this difference can be used to calculate the distance to the object. These studies refuted much of the Greek view of the heavens. For one thing, the comet was farther away than the Moon, so it had to be heavenly and not earthly. Secondly, the path of the comet was not part of a circle, so heavenly objects need not all move in circles. Finally, the path of the comet of 1577 was such that it must travel through the crystalline spheres. Hence, something other than crystalline spheres must be holding the Sun, Moon, planets, and stars in space.

❖ Materials

German metallurgist Lazarus Ercker [b. Annaberg (Germany), 1530, d. Prague (Czech Republic), 1594] publishes *Beschreibung Allerfürnemisten mineralischen Ertzt und Bergwerksarten* ("description of mineral ores and mining techniques"). See also 1556 MATR.

1575

☛ Communication

Leiden University (Netherlands) is founded as a secular

institution open to all faiths. See also 1583 COMM.

Philip II of Spain founds the Academia de Ciencias Matemáticas in Madrid. See also 1560 COMM; 1603 COMM.

❖ Materials

French ceramist Bernard Palissy [b. Saintes, France, c. 1510, d. Paris, c. 1589] rediscovers the method of covering pottery with another material such that when the pot is fired it will have a hardened coat,

called enamel. See also 1580 MATR.

Σ Mathematics

Arithmetoricorum libri duo by Francesco Maurolico [b. Messina, Sicily, September 16, 1494, d. Messina, July 21, 1575] includes the proof by mathematical induction that the sum of the first n odd numbers is n^2 . This result was known by early Pythagoreans, but it is assumed that their proof was based on a simple geometric argument concerning the dot patterns used in figurate numerals. Mathematical induction is a method of proof based on the idea that if it can always be shown that a true statement about a number remains true when the number is increased by 1, then the statement must be true for all numbers. See also 1321 MATH.

♥ Medicine & health

In his book *Catalogue of Common Places*, Johannes Thomas Freigius [b. (Switzerland), 1543, d. 1583] uses the term *psychologia* ("mind study"). He reintroduces the term in another book in 1579. By 1588 the term will be picked up by a French theologian. By 1590 the word *Psychology* will be used as the title of a book in German.

1576

★ Astronomy

Prognostication everlasting by Leonard Digges contains an appendix written by his son Thomas in which the heliocentric system of Copernicus is placed in a system of stars occupying infinite space. See also 1543 AST.

Tycho Brahe starts his observations at his observatory at Uraniborg on the island of Hven in the Sont near Copenhagen, Denmark. His work is funded by King Frederick II of Denmark and Norway. See also 1572 AST; 1577 AST.

→ Transportation

Robert Norman [b. Bristol, England, c. 1550] shows that a compass needle, when allowed freedom to swing in any direction, will point below the horizon. See also 1190 TRAN; 1744 TRAN.

1577

★ Astronomy

Tycho Brahe tries to determine the distance of the great comet of 1577 from Earth using parallax. His crude observations are good enough to demonstrate that the comet has to be at least four times as distant as the Moon, proving that a comet is not an atmospheric phenomenon. See also 1550 AST.

॥ Food & agriculture

Barnaby Googe [b. Lincolnshire, England, June 11, 1540, d. February 1594], in his *Four Books of Husbandry*, proposes the use of artificial prairies and stresses the importance of weeding. See also 1701 FOOD.

❖ Materials

Prosperity in England during the Elizabethan Age, as described by William Harrison in *Description of England*, includes chimneys instead of smoke holes, glazed windows instead of wooden lattices, regular beds instead of straw pallets, pewter plates instead of

wooden platters, and tin or silver spoons instead of wooden ones. English gardens, Harrison reports, now include flowers and “rare and medicinal” herbs. *See also* 1274 FOOD.

→ Transportation

The use of the Dutchman’s log for measuring the speed of a ship is known. Unlike the log-and-line, it uses marks on the side of the ship. The interval between the first and last mark passing a floating object indicates the measure of the ship’s speed. *See also* 1573 TRAN; 1710 TRAN.

1578

I Tools

Jacques Besson publishes a second edition of *Theatrum instrumentorum et machinarum* with some revised illustrations and more text. In it he describes improvements on the lathe, including adding a lead screw and nut and controlling the workpiece by templates and cams, making it possible to turn more diverse and intricate shapes. *See also* 1569 TOOL; 1701 TOOL.

1579

Σ Mathematics

Canon-mathematicus by French mathematician Franciscus Vieta (François Viète) [b. Pitou, France, 1540, d. Paris, February 23, 1603] argues for decimal representation of numbers and extends the trigonometric tables of Rheticus to each second of a degree. *See also* 1461 MATH; 1596 MATH.

♥ Medicine & health

The first glass eyes are probably made about this time.

I Tools

The ribbon loom, a loom for narrow fabrics that can weave several pieces at a time, is invented. *See also* 1596 TOOL.

1580

↗ Biology

Italian botanist Prospero Alpini [b. Venice (Italy), November 23, 1553, d. Padua (Italy), November 23, 1616] becomes the first scientist to learn that plants, like animals, have two sexes (although this was probably known to the common farmer and gardener for certain plants centuries earlier). *See also* 1583 BIO.

❖ Materials

The custom of adding pockets to trousers is introduced. *See also* 1700 MATR.

Bernard Palissy’s *Discours admirables de l’art de terre, de son utilité, des esmaux et du feu* (“admirable discourse on pottery and its uses, on enamels, and on fire”) covers a wide range of geological and chemical ideas. *See also* 1575 MATR.

1581

⊕ Earth science

Robert Norman’s *The New Attractive* relates his discoveries on Earth’s magnetism, especially magnetic dip. *See also* 1544 EAR; 1600 EAR.

✿ Physics

According to a widely reported legend (although not verified), 17-year-old Galileo observes that each lamp in the cathedral of Pisa swings in the same amount of time regardless of the size of the swing (amplitude) for that lamp.

Although this is not accurate, it is close to true, and Galileo continues to make this claim about pendulums all his life. This observation leads to pendulum-driven clocks. *See also* 1494 TOOL; 1602 TOOL.

1582

★ Astronomy

On the advice of astronomer Christoph Clavius [b. Bamberg (Germany), 1537, d. Rome, February 6, 1612], Pope Gregory XIII reforms the calendar, dropping the ten days between October 4 and October 15; in the new Gregorian calendar, century years that are not divisible by 400 will no longer be leap years (as they were in the Julian calendar). *See also* 46 BCE AST; 1583 COMM.

↗ Energy

Dutchman Peter Morice installs a water turbine in London that powers a pump that supplies the city with water from the Thames River. *See also* 1629 ENER.

1583

↗ Biology

De plantis (“on plants”) by Italian doctor and botanist Andrea Cesalpino [b. Arezzo (Italy), June 6, 1519, d. February 23, 1603] gives a classification scheme for plants based on roots and fruits. *See also* 1580 BIO; 1676 BIO.

⌚ Communication

The University of Edinburgh is founded in Scotland as a secular institution. *See also* 1575 COMM.

French scholar Joseph Justus Scaliger [b. Agen, France, August 5, 1540, d. Leiden, Holland, January 21, 1609] devises the Julian day count, which sets January 1, 4713 BCE as day 1; he numbers all days subsequently from that, so January 1, 2005, is Julian day 2,453,371. The system is called

Julian in honor of his father, Julius Caesar Scaliger.

1584

★ Astronomy

Dell' infinito, universo e mondi (“of infinity, the universe, and the world”) by Giordano Bruno [b. Nola (Italy), 1548, d. Rome, February 17, 1600] gives the opinion that stars have planetary systems and that the universe is infinite. In this same year, Bruno’s *La cena delle ceneri* (“the dinner of ashes”) defends the Copernican view of the solar system, although for mystical instead of astronomical reasons.

☛ Communication

A prince of the Ming dynasty, Chu Tsai-Yü, invents equal temperament in music, described in his book *A New Account of the Science of the Pitch-Pipes*. Equal temperament — which is the equal spacing of the 12 semitones in an octave — is necessary to reconcile differences in harmony between the intervals of a fifth and an octave, known since the time of Pythagoras, although equal spacing makes each note slightly flat. *See also* 1636 COMM.

☛ Transportation

Dutchman Humphrey Bradley is brought to England to help design and construct a harbor for Dover. *See also* 1588 FOOD.

1585

■ Construction

Pope Paul V builds the Acqua Marcia-Pia aqueduct, the first new aqueduct in Italy since the Aqua Alexandrina of 226, 1644 years earlier. *See also* 226 CE CONS.

❖ Materials

Mathematician Thomas Harriot [b. Oxford, England, 1560, d. London, July 25, 1621] and Bohemian metallurgist Joachim Gans (the first Jew in the English colonies of the New World) set up the first scientific laboratory in the New World, a small smelting operation designed to test ores for gold and silver. It is part of Sir Walter Raleigh’s first colony on Roanoke Island (Virginia), a settlement that is evacuated in 1586. A second colony in the same region is started in 1587, but disappears without a trace. Remains of the Harriot-Gans laboratory will be discovered in 1991. *See also* 1520 MATR; 1614 CHEM.

Σ Mathematics

De thiende (“the tithe, or tenth”), also known by its French translation as *La disme*, by Flemish mathematician and physicist Simon Stevin (Stevinus) [b. Bruges, Flanders (Belgium), 1548, d. The Hague, Holland, c. March 1620] is a systematic account of how to use decimal fractions.

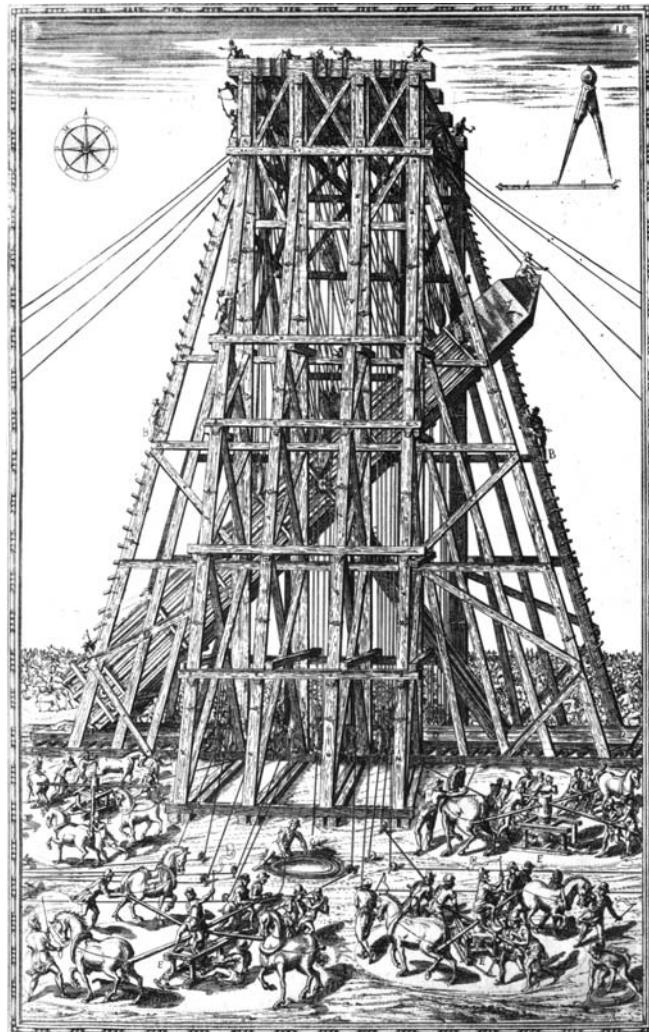
✿ Physics

In *On mechanics* Giovanni Battista Benedetti [b. Venice (Italy), August 14, 1530, d. Turin (Italy), January 20, 1590] criticizes Aristotle’s views on motion and discusses the “impetus” theory.

1586

■ Construction

A 327-ton Egyptian obelisk that the Romans had brought from Egypt in ancient times is raised to a vertical position by a team led by Domenico Fontana [b. Melide, Switzerland, 1543, d. Naples (Italy), 1607].



RAISING THE OBELISK IN ST. PETER'S SQUARE The scaffolding had to be strong to raise a 370-ton obelisk, but Fontana’s scheme was successful. If you visit Rome today, you can still see the obelisk standing in the square.

♥ Medicine & health

Walter Raleigh imports the smoking habit into England from Virginia. *See also* 1550 MED.

Arcangelo Piccolomini [b. (Italy), 1525, d. 1586] distinguishes between the outer cortex and white matter of the cerebral hemispheres. *See also* 1573 MED.

✿ Physics

Simon Stevin shows that the pressure of a liquid on a given surface depends on the height of the liquid and on the area of the surface.

Simon Stevin discovers the theorem of the triangle of forces (addition of vectors). *See also* 1220 PHY; 1589 ENER.

Simon Stevin performs the key experiment in understanding

gravity, dropping two different weights at the same time and noting that they strike the ground at the same time. *See also* 1450 PHY; 1604 PHY.

1588

★ Astronomy

Tycho Brahe's *De mundi aetherei recentioribus phaenomenis* ("about recently observed phenomena in the aether sphere") rejects the idea of crystalline spheres holding the stars based on his observations of the comet of 1577. He also develops a theory for the solar system in which the Sun and Moon revolve about Earth, but the planets Mercury, Venus, Mars, Jupiter, and Saturn revolve about the Sun. *See also* 1577 AST.

● Communication

Timothy Bright [b. Sheffield, England, 1551, d. Shrewsbury, England, November 1615] adapts the shorthand developed by Marcus Tullius Tiro to the English language. *See also* 70 BCE COMM.

● Food & agriculture

In *Le diverse et artificiose machine del Capitano Agostino Ramelli* ("the various and ingenious machines of Captain Agostino Ramelli") Agostino Ramelli [b. Ponte Tresa (Italy), 1531, d. c. 1608] makes detailed drawings of his concept of a flour mill that would grind grain using a corrugated roller with spiral grooves, the first known roller mill. The feed hopper has its throughput regulated by the speed of the

millstone, an early example of a feedback mechanism. Ramelli also designs a system of vibrating screens, now known as a middlings purifier, to remove bran from the flour. *See also* 1300 FOOD; 1662 FOOD.

next four centuries. It is the first book to illustrate a fully developed windmill with all its gears and working parts. *See also* 1502 ENER.

1589

■ Construction

English poet Sir John Harington [b. 1561, d. 1612] designs a flush toilet at his home at Kelston, near Bath (as described in his 1589 *The Metamorphosis of Ajax*) that contains water in the bowl that can be flushed with water from a cistern into a nearby pit. A similar toilet is installed in Richmond Palace by Harington's aunt, Queen Elizabeth I. *See also* 1778 CONS.

● Tools

Agostino Ramelli's *Le diverse et artificiose machine* becomes one of the most popular illustrated machine books ever, reprinted and recopied for the

Replacing Aristotle's physics

Aristotle was the first to formulate a unified system to explain physical phenomena. His thinking dominated philosophy and science for an enormously long time, almost 1900 years. His ideas about physics remained unchallenged until the Middle Ages, when such scholars as Jean Buridan, William of Ockham (a.k.a. Occam), Nicolas Oresme, and Nicholas of Cusa started questioning and refining his assumptions.

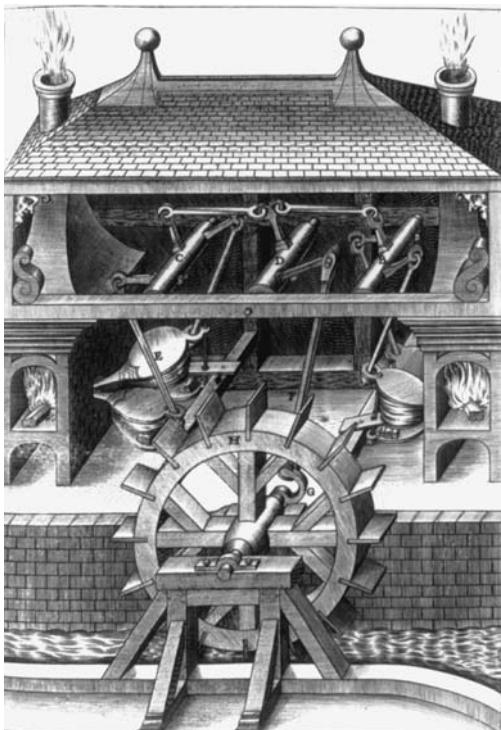
Aristotle distinguished between "natural" and "unnatural" motion. Bodies moving naturally would move either up or down. Horizontal motion, as in a flying projectile, Aristotle termed "unnatural." Natural motion of a body was a consequence of the amount of the prime substances — earth, water, air, and fire — present in that body. Each of these elements had a natural place to which it would move if unimpeded. A stone falls because it contains earth; steam rises because it contains fire. The natural motion of celestial objects he viewed as different from motion on Earth; it was circular motion, with no beginning or end.

Horizontal motion resulted from a pull or push acting on the object. To explain the motion of a projectile, which apparently is not pushed after release, Aristotle assumed that the air flowing around it and filling up the empty space created behind it would push the projectile continuously. Aristotle also noticed that bod-

ies in a denser medium, such as water, fall at a slower speed than those in a less dense medium, such as air. From this he concluded that an object would fall at infinite speed in a vacuum; since he believed that infinite speed was not possible, an absolute vacuum could not exist.

In 1586 Simon Stevin showed that the speed of falling bodies is not proportional to their weight, as Aristotle had assumed, but that all bodies fall at an equal rate. Galileo did similar experiments a few years later, often timing balls rolling down on inclined planes to slow down their "falling motion." Galileo deduced the following laws from his experiments: 1) Any body moving on a horizontal plane will continue at the same speed unless a force opposes it. 2) In a vacuum, all bodies fall at the same rate, no matter what their weight or constitution. 3) A body falling freely or rolling down an inclined plane undergoes uniform acceleration.

Newton generalized Galileo's ideas, showing that Aristotle's "unnatural motion" is in matter of fact the norm, and rising and falling bodies act thus because of forces. Interestingly, since Aristotle's ideas about motion correspond to what we observe in daily life, they remain as underlying assumptions for people unfamiliar with Newton's laws. Since we do not observe motion in a vacuum or without friction, objects on Earth continue to appear to obey Aristotle's laws of motion.



A MECHANIZED MILL FROM RAMELLI The machine books, such as that of Agostino Ramelli, reveal how the mills of the Renaissance worked. Here the reader can see how a water wheel powers several bellows to keep fires hot.

Energy

Simon Stevin files for a patent on a windmill that provides for an alternate drive using horses when the wind dies down. About this time 101 similar patents are filed in Holland for other improvements on the windmill. *See also* 1586 PHY.

Food & agriculture

Humphrey Bradley proposes to dig canals that would drain the Fenn region of England using gravity alone, a project not actually completed until the next century. *See also* 1588 FOOD.

Materials

In England iron makers begin to patent methods for using one or another form of coal at different stages in the manufacturing process, although none of these early patents seems to have replaced char-

coal in the actual smelting. *See also* 1611 MATR.

Tools

The Reverend William Lee, an English clergyman, invents the first knitting machine, a predecessor of the stocking frame. He is probably also responsible for the spring-beard needle, one of the two main types of knitting needle. *See also* 1758 TOOL.

Transportation

Giovanni Battista della Porta's *Natural Magic* is the first Western book to mention kites and kite flying. *See also* 1232 COMM.

1590

Communication

The *Mercurius gallo-belgicus*, a newspaper, starts publication in London; it reports on

developments on the Continent and is published until 1610. *See also* 748 COMM; 1605 COMM.

Construction

Giacomo della Porta and Domenico Fontana complete the dome on St. Peter's in Rome, making it the largest church in the world; the church was designed in 1503 by Donato Bramante but mostly completed by Michelangelo, who also designed the dome. *See also* 1546 CONS; 1626 CONS.

Food & agriculture

Italian engineer Ascanio Fenici, sponsored by Pope Sixtus V, who has worked for over three years on draining the Pontine Marshes, sees his project abandoned because of the death of the pope. Although several other plans will be developed for draining the

marshes, this is the last actual work on the project until the 1930s, when Mussolini's government finally accomplishes the task. *See also* 1514 FOOD.

Physics

Galileo's *De motu* ("on motion") refutes Aristotelian physics and relates his experiments with falling bodies. It reports on experiments showing that without friction falling bodies accelerate at the same rate and moving bodies on a flat surface continue at the same speed. *See also* 1586 PHY; 1604 PHY.

I Tools

Dutch lens maker Zacharias Janssen [b. 1580, d. 1638] and his father Hans probably invent the compound microscope about this time. Because Zacharias was only ten years old in 1590, some authorities propose that 1595 is more likely. *See also* 1609 TOOL.

Transportation

Robert Norman's *The Safe-garde of Sailors*, a translation from the Dutch, is a navigational manual that contains maps of the appearance of the coast as seen from the sea.

1591

Construction

The Rialto bridge in Venice combines the segmental and the elliptical arch style of construction. *See also* 1569 CONS.

Earth science

English mathematician Thomas Harriot is the first European known to note that all snowflakes are either six-pointed or six-sided, but he does not publish this observa-

tion. The hexagonal nature of snowflakes was well-known in China, however, from at least the second century BCE. *See also* 1611 PHY.

Σ Mathematics

Isagoge in artem analyticam (“introduction to the analytic art”) by Franciscus Vieta is the first work in mathematics to use letters for variables and constants (vowels for variables and consonants for constants). *See also* 1631 MATH.

1592

★ Astronomy

Korean astronomers observe a nova in the constellation Cetus and track its changes over a 15-month period. *See also* 1577 AST; 1604 AST.

I Tools

About this time Galileo develops a thermoscope, a primitive form of thermometer using air instead of a liquid; it is grossly inaccurate, but forms the basis for measuring temperature for the next ten

years at least. *See also* 1612 TOOL; 1654 TOOL.

1593

❖ Materials

Galileo’s *Della scienza mechanica* (“on mechanical knowledge”), which he writes after he has been consulted regarding shipbuilding problems, is one of the first books to deal scientifically with the strength of materials. Unpublished in his time, it is widely circulated in manuscript. *See also* 1536 TRAN; 1638 MATR.

Σ Mathematics

The first description of a modern Chinese abacus appears in China.

1594

Σ Mathematics

John Napier [b. Edinburgh, Scotland, 1550, d. Merchiston Castle, near Edinburgh, April 4, 1617] has the idea that will result in the invention of loga-

rithms (after 20 years’ work). *See also* 1614 MATH.

I Tools

The Republic of Venice (Italy) grants a patent to Galileo for a device for raising water. *See also* 1474 COMM.

1595

❖ Communication

Gerardus Mercator’s *Atlas sive cosmographicae*, published posthumously, contains a collection of detailed maps of Europe. *See also* 1570 COMM.

Σ Mathematics

Bartholomaeus Pitiscus [b. Grunberg (Germany), August 24, 1561, d. Heidelberg (Germany), July 2, 1613] is probably the first to use the word *trigonometry* in print. *See also* 1579 MATH; 1596 MATH.

❖ Transportation

The Dutch invent the *flyuytschip* (“flute”), the most sensible cargo ship of the time, cheap to build and operate and yet able to carry a

large cargo. *See also* 1536 TRAN.

1596

★ Astronomy

David Fabricius [b. Esens (Germany), March 9, 1564, d. Osteel, Ostfriesland, May 7, 1617] discovers the star later named Mira, the first known variable star. *See also* 1638 AST.

Mysterium cosmographicum (“the mystery of the universe”) by Johannes Kepler includes the concept that the sphere of each planet is inscribed in or circumscribed about one of the five Platonic regular solids, which explains why there are exactly five planets (six counting Earth), all that were known at the time.

❖ Biology

The *Herbal, or Generall Historie of Plantes*, of English botanist John Gerard [b. 1545, d. London, February 1612] is the most important survey of botanical knowledge of its time. *See also* 1539 BIO.

Galileo and measurement

Before the 17th century, it was almost impossible to measure most things precisely. Although length and mass could be measured quite well, chemists did not realize the power of the balance, which was used primarily by assayers. Time could only be measured in large intervals. Temperature and fluid pressure could not be measured in numbers at all.

Galileo was at the heart of changing this situation. In 1581, when he was only 16, he noticed that the period of a pendulum appeared to be controlled solely by its length. This discovery led to the manufacture of good pendulum clocks by the end of the 17th century. Galileo himself had to time some of his physics

experiments with his own pulse, however. In 1586, Galileo published his invention of a hydrostatic balance. In 1600, Galileo built the first primitive tool for measuring temperature. This was refined into a workable thermometer over the course of the 17th century and put into modern form by Fahrenheit in 1714. It was Galileo who suggested to Torricelli the investigation that led to the barometer. Galileo’s telescopes inspired others to build astronomical telescopes, which in turn led to the micrometer. Telescopes used in surveying also inspired the vernier system for making accurate measurements of angles.

None of these tools for measurement was sufficiently accurate to contribute to the development of science in Galileo’s lifetime. Shortly after his death in 1642, however, the new tools helped create modern science.



Johannes Kepler

[b. Württemberg (Germany), December 27, 1571, d. Regensburg, Bavaria (Germany), November 15, 1630]

"Just as the eye was made to see colors, and the ear to hear sounds, so the human mind was made to understand, not whatever you please, but quantity," wrote Kepler. Kepler based his investigations on careful observations and complex mathematics, but always with a mystical bent, perhaps from his work as an astrologer. As Tycho Brahe's assistant and successor, he used Tycho's careful observations to discover the three mathematical laws that describe a planet's orbit, the speed at which it travels, and the time it needs to complete one revolution around the Sun. He proved that Earth and other planets travel in orbits that are ellipses, not circles as had been believed since ancient times. And he showed that the speed of a planet in its orbit is not uniform, but decreases as its distance from the Sun increases, thus overthrowing another long-held belief. Kepler also was a founder of the modern science of optics. He was the first to correctly explain how people see — he noted that the pupil of the eye functions as a diaphragm and that light rays are focused on the retina. He also explained why eyeglasses help people see better. After Galileo Galilei sent him one of the first telescopes, he explained how the instrument works and improved its design.

* The kindes.

THere be diuers kinds of Angelicaes; the garden Angelica; that of the water, and a thirde sorte wilde growing vpon the land.

I *Angelica sativa.*
Garden Angelica.



2 *Angelica sylvestris.*
Wilde Angelica.



A PLANT DRAWING FROM GERARD'S HERBAL The *Herbal* depicted the whole plant, including blossoms and roots, for complete identification. Garden angelica is sometimes used in herbal medicines, but more often is used for flavoring or is candied.

Pen Ts'ao kang mu (a.k.a. *Bencao gang mu*, "the great herbal," or "great pharmacopoeia") by Chinese botanist Li Shih-Chen a.k.a. Li Shizhen, b. 1518, d. 1593], published posthumously, contains descriptions of more than 1000 plants and another 1000 animals along with 8000 medicinal uses for them.

❖ Materials

Li Shih-Chen's *Pen Ts'ao kang mu* gives one of the clearest descriptions of how to distill wine into spirits, a technique known to the Chinese since about the seventh century.

Σ Mathematics

The *Opus palatinum de triangulis* ("the Palatine work on triangles") by Rheticus is published posthumously. It contains trigonometric tables for the values of the six standard trigonometric functions. See also 1579 MATH; 1619 MATH.

I Tools

Anton Müller, the inventor of the ribbon loom, is strangled in Danzig (Gdańsk, Poland) when workers fear that his invention will put them out of work. See also 1579 TOOL; 1604 TOOL.

✈ Transportation

Admiral Visunsin of Korea develops the first ironclad warship. *See also* 1595 TRAN; 1845 TRAN.

1597

★ Astronomy

In correspondence with Kepler, Galileo admits that he has come to accept the Copernican scheme of the solar system. *See also* 1543 AST; 1600 AST.

⚗ Chemistry

Alchemia ("alchemy") by Andreas Libavius (Andreas Libau) [b. Halle, Saxony (Germany), 1540, d. Coburg, Bavaria (Germany), July 25, 1616] is one of the first important textbooks in chemistry, describing the preparation of hydrochloric acid, tin tetrachloride, and ammonium sulfate. *See also* 1608 CHEM.

1598

✈ Transportation

Philip III of Spain offers a prize and a lifetime pension to anyone who can discover a way to find the longitude at sea. *See also* 1533 TRAN; 1616 EAR.

1599

☒ Biology

Italian naturalist Ulisse Aldrovandi [b. Bologna (Italy), 1522, d. Bologna, May 10, 1605] starts publishing his first volume of *Natural History* (three volumes), the first serious work in zoology.

🏗 Construction

The Globe Theater, home to

nearly half of William Shakespeare's plays in their first productions, is built by the Lord Chamberlain's Men on the south bank of the Thames in London. Most of the audience of 3000 stands in an uncovered pit, although there are benches in roofed galleries for those who can afford them.

1600

★ Astronomy

After Tycho Brahe moves to the court of Holy Roman Emperor Rudolph II in Prague in 1599, Kepler begins assisting Tycho at the Prague observatory.

Giordano Bruno, the Italian philosopher accused of heresy mainly because of his adherence to the theory that Earth revolves around the Sun, is burned at the stake in Rome, February 17. His connection with the Copernican theory is said to have helped cause Galileo's recantation of a moving Earth. *See also* 1597 AST.

🌐 Earth science

De magnete ("concerning magnetism") by physician, physicist, and earth scientist William Gilbert suggests that Earth is a great spherical magnet and reports on various

substances that can be used to produce static electricity. It is the first treatise on physical science based entirely on experimentation. *See also* 1581 EAR; 1630 PHY.

🍴 Food & agriculture

The doughnut originates in Holland, although the hole is not removed from the center until the middle of the 19th century.

Italian scientist Zimara recommends a mixture of snow and saltpeter as a refrigerating substance for preserving food.

Σ Mathematics

Franciscus Vieta finds a solution to the "fourth Apollonian problem," which is constructing a circle touching three given circles.

Adriaen Anthoniszoon and his son calculate π as 3.1415929 (the correct value to that many places is 3.1415927).

♥ Medicine & health

De formato foetu ("on the formation of the fetus") by Italian anatomist Hieronymus Fabricius ab Aquapendente (a.k.a. Geronimo Fabrizio) [b. May 20, 1537, d. Padua, Italy, May 21, 1619] is the first study of late fetal stages in animals.

I Tools

King Henri IV orders the first modern Parisian water supply system, with pumps raising water from the Seine from under one of the arches of Pont Neuf. The pumps, designed and installed by Flemish engineer Jean Lintlaer, are powered by an undershot water wheel. After the royal palaces are supplied, surplus water is offered to the public (with fees paid to support the system). *See also* 1400 TOOL.

1601

★ Astronomy

Kepler is appointed Tycho Brahe's successor as Imperial Mathematician to the Holy Roman Emperor, Rudolph II, in Prague. *See also* 1600 AST.

♥ Medicine & health

De vocis auditusque organis historia anatomica ("on the anatomy of the voice and hearing") by Julius Casserius [b. 1561, d. 1616] is an illustrated work on the larynx and the ear. *See also* 1561 MED.

✈ Transportation

The first Swedish canal is built, one of the early canals of Europe. *See also* 1642 TRAN.



William Gilbert

[b. Colchester, Essex, England, May 24, 1544, d. London, November 30, 1603]

Gilbert's book *De magnete* (in English called *On the Magnet, Magnetick Bodies Also, and on the Great Magnet the Earth*), published in 1600, is among the seminal works of the Scientific Revolution. Gilbert describes his experiments with lodestones and compasses, gives methods of making iron display magnetic effects, introduces the concept of magnetic poles, and recognizes the magnetic field of Earth.

1602

★ Astronomy

Tycho Brahe's *Astronomiae instauratae pro gymnasista* ("introduction to the new astronomy"), published posthumously, contains detailed positions for 777 stars and a description of the 1572 supernova. *See also* 1603 AST; 1627 AST.

Pendulum myths

You often see statements to the effect that "Galileo invented the pendulum in 1581, greatly improving the accuracy of clocks." This is simply not true. Instead, sometime in the 1580s or later, Galileo, observing lamps swinging and other motion of this type, decided to claim that the time of a pendulum's swing (its period) depends only on the length, not the size (amplitude) of the swing. Some historians of science think that Galileo did not actually believe this statement (it is not true), but that he claimed it because it seemed more dramatic than the truth, which is that for small amplitudes the period is very close to dependent only on the length of the pendulum. Galileo suggested that this concept might be used to make a more accurate clock, but he never got around to constructing one (although his son experimented with pendulum clocks). Interestingly, Leonardo da Vinci seems to have had the same idea a century earlier than Galileo, but he never got around to trying to build a clock using a pendulum either.

Since the period of the pendulum varies somewhat with the amplitude, a clock using a pendulum for regulation needs a compensating mechanism. Unwittingly, Galileo suggested the idea that led to the first good compensating method. He called the attention of mathematicians to a curve called the cycloid, which is the curve generated by a point on the rim of a rolling wheel. Mathematicians in the 17th century were very interested in the properties of the cycloid. In a famous incident in 1658, the mathematician Blaise Pascal, who had otherwise retired from mathematics for religious reasons, used solving the properties of the cycloid to keep his mind off a toothache. He published the results, which led to the realization by Christiaan Huygens that the cycloid is an isochrone (a.k.a. tautochrone) — a curve through which an object falls in the same amount of time no matter how high.

Again, the myth and the reality are somewhat different. The myth is that Huygens was unable to make a good pendulum clock until he found the tautochrone. In reality, Huygens made

Chemistry

Vincenzo Casarido discovers barium sulfide. *See also* 1597 CHEM; 1608 CHEM.

I Tools

On November 29 Galileo writes in a letter that pendulums of the same length swing with the same time no matter what the amplitude, the first written evidence of this con-

cept. *See also* 1581 PHY; 1641 TOOL.

1603

★ Astronomy

Uranometria by Johann Bayer [b. Rain (Germany), 1572, d. Augsburg, Bavaria, March 7, 1625] introduces the method of describing the locations of stars and of naming them

with Greek letters and the constellation they are in that continues to be used today. This publication is the first attempt at a complete celestial atlas. *See also* 1602 AST.

Communication

The early scientific society Accademia dei Lincei (Academy of Lynceus or Lynxes or Lynx-Eyed) is founded in Rome by

the first good pendulum clocks with no thought of the cycloid. When he showed that the cycloid was a tautochrone — two years later — he made a few clocks that used this idea, but they were clumsy and did not work as well as those that just used a pendulum with small amplitude. Pendulum clocks that did not employ the cycloid were relatively accurate, but keeping the beat exact was still a problem.

A few years later a series of little-known English craftspeople found various ways to handle the problems of the pendulum. William Clement developed an escapement that kept the amplitude of the swing small. Nearly 50 years later George Graham developed an escapement that nudged the pendulum at one point and braked it at another to make the whole operation more accurate.

In addition to the ordinary pendulum, a different kind of pendulum, called a balance wheel, was used in small clocks from early in the 15th century. Subject to the same problems as the ordinary pendulum, the balance wheel also needs compensation to make it accurate. George Graham found a way to do this, and 50 years later another obscure Englishman, Thomas Mudge, found a better way, one used in balance-wheel watches and small clocks to the present day.

Even if Galileo had been correct in asserting that the pendulum swing depends only on its length, the pendulum could not be a perfect timekeeper because its length varies with temperature. The same English craftspeople who found ways to correct the variation caused by changing amplitude also found clever ways to correct the variation caused by temperature changes. By the middle of the 18th century, the best pendulum clocks kept nearly perfect time, losing seconds per month. But the accuracy of these mechanical pendulum clocks was very much superseded in the 20th century — first by accurate electric clocks, then by clocks in which the expansion and contraction of a quartz crystal acted as the "pendulum" for an electric clock, and finally by clocks that used the natural vibrations of molecules as pendulums, the so-called "atomic" clocks.

Federigo Cesi [b. Rome, 1585, d. Acqua Sparta, Italy, 1630]. Still active today, it may have been named for Lynceus, the sharp-eyed Argonaut with telescopic vision, although the lynx is its symbol. *See also* 1560 COMM; 1657 COMM.

Alexander Top in *The Olive Leaf* proposes that God created the Hebrew alphabet by using the first letters of 22 of the things He created during the first week.

Energy

Hugh Platt discovers coke, a charcoal-like substance produced by heating coal. *See also* 1307 ECOL; 1709 MATR.

Food & agriculture

The Jerusalem artichoke, a sunflower tuber unrelated to the artichoke and native to North America, is mentioned by Champlain, founder of Quebec, as being cultivated by Native Americans.

Mathematics

Pietro Antonio Cataldi [b. Bologna (Italy), April 15, 1548, d. Bologna, February 11, 1626] finds the sixth and seventh perfect numbers, which are 8,859,869,056 and 137,438,691,328. *See also* 1536 MATH.

Medicine & health

Hieronymus Fabricius's *De venarum ostioliis* ("on the valves in the veins") is a detailed study of valves in veins. The functions of these valves will not be understood, however, until 1616.

Italian physician Sanctorius Sanctorius (Santorio Santorio) [b. Justinopolis (Yugoslavia), March 29, 1561, d. Venice (Italy), March 6,

1636] describes his device that uses a pendulum for counting pulse beats. *See also* 1707 MED.

1604

Astronomy

Kepler observes and describes a supernova in the constellation Ophiuchus, also seen by Korean and Chinese astronomers. It is not quite as bright as Venus and lasts for 12 months. *See also* 1592 AST.

Chemistry

Alchemist Johan Thölde edits or writes *Triumph-wagen des antimonii* ("triumphal chariot of antimony"), a detailed description of the metal antimony and the uses of its compounds; Thölde attributes the work to a 16th-century monk named Basil Valentine.

Physics

Kepler's *Ad vitellionem paralipomena quibus astronomiae pars optica traditor* ("the optical part of astronomy") describes how the eye focuses light and shows that the intensity of light falls as the square of distance from the source. *See also* 1270 PHY.

Galileo announces in a letter to Paolo Sarpi that a body falling freely increases its distance as the square of the time since the fall started, which is correct, and that the velocity is proportional to distance, which is incorrect. Galileo corrects his error in 1609. *See also* 1545 PHY.

Tools

Willem Diericks Van Sonneveldt develops a machine that can produce up to 24 ribbons. It is operated by just one per-

son. *See also* 1596 TOOL; 1607 TOOL.

1605

Communication

Advancement of Learning by Francis Bacon argues against magic and encourages the development of scientific methods. *See also* 1620 COMM.

Abraham Verhoeven starts publication in Antwerp of the first newspaper on the European Continent, the *Nieuwe Tijdingen*. *See also* 1590 COMM.



Francis Bacon

[b. London, January 22, 1561, d. London, April 9, 1626]

Bacon's main influence on science was his emphasis on developing general laws that apply to observations, laws formed by thoughtfully collecting as many instances as possible and abstracting the laws in a process called induction. As a scientist himself, Bacon was nearly correct in explaining heat, although he reversed cause and effect by suggesting that the expansion of heated materials causes movements of their particles.

1606

Astronomy

Kepler's *De stella nova* ("on a new star") describes the nova first observed in 1604, including its astrological significance. *See also* 1604 AST.

Energy

Giovanni Battista della Porta publishes *Spiritali*, in which he describes an apparatus to empty a water container using steam pressure. *See also* 1504 ENER.

1607

Construction

The Pont Neuf is completed; it is the oldest bridge still standing in Paris. *See also* 1507 CONS.

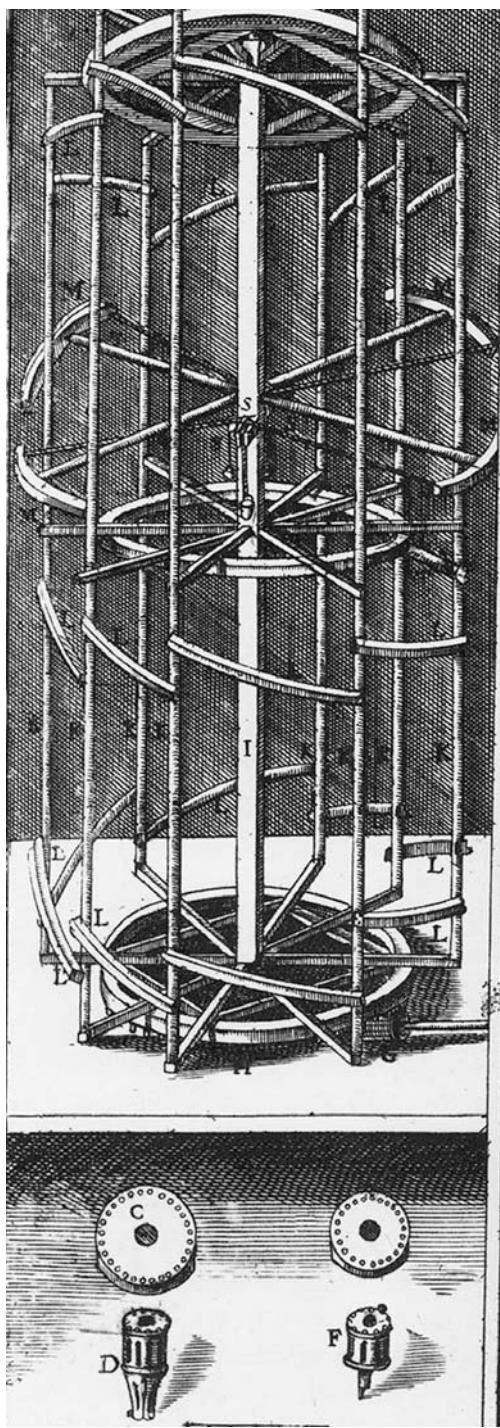
Tools

The machine book *Nuovo teatro di machine et edificii* ("new theater of machines and buildings") by Vittorio Zonca [b. 1568, d. 1602] is published in Padua (Italy). A second edition appears in 1621 and a third in 1656. The book describes, among other machines, a machine for throwing silk using waterpower, although at this time in Piedmont the design for such a machine is a state secret. The book does not seem to affect technology immediately. Similar machines will not be built in England until the next century. *See also* 1604 TOOL.

1608

Chemistry

Ein kurser tractat von der natur der Elementum ("an alchemical tract on the transmutation of elements") by Dutch physicist Cornelius Drebbel [b. Alkmaar, Holland (Netherlands), 1572, d. London, 1634] anticipates the production of oxygen by heating saltpeter. *See also* 1597 CHEM.



FROM ZONCA'S MACHINE BOOK A water wheel is the power source for a device that is a multiple spinning mill, a rotating frame that used to spin several threads at the same time.



II Food & agriculture

Jan Andriaanszoon (Leeghwater) drains a large lake named Bamestra to produce a polder (now called Beemster) in the Low Countries (Netherlands) using improved multistaged water lifts that employ two to four scoops in tandem. A polder is a low-lying region in the Netherlands kept free of surface water by windmill-driven pumps or other drainage systems. See also 1556 FOOD; 1628 CONS.

I Tools

German-Dutch optician Hans Lippershey [b. Wesel (Germany), c. 1570, d. Middelburg, Zeland (Netherlands), c. 1619] invents the telescope. See also 1611 TOOL.

1609

★ Astronomy

Galileo builds his first telescope and, with modifications and improvements, eventually obtains a magnification of about 30 power. It is made of wood and leather, is 9.8 cm (3.9 in.) long, and enlarges objects 21 times.

Kepler's *Astronomia nova* ("new astronomy") contains his views that the planets revolve around the Sun in elliptical orbits and that these orbits sweep out equal areas in equal time intervals. These two observations later contribute to the confirmation of Newton's theory of gravity. See also 1080 AST; 1619 AST.

Thomas Harriot uses a simple telescope to sketch the Moon. See also 1610 AST.

Galileo and his telescope

In 1609 Galileo heard of a new invention shown at an exposition in Venice. It was an "optical tube" that would bring distant objects close. Galileo set out to reinvent such an instrument and quickly succeeded. During the next few months Galileo made some of the most important discoveries of astronomy. His observations also established the Copernican system as physical reality.

He observed the craters and mountains on the Moon and was struck by the Earthlike appearance of the Moon's landscape. He also noticed that the dark side of the Moon was faintly illuminated by Earth, a phenomenon known as Earthshine. With this he proved that Earth "shines" as much as the other planets and thus must reflect the light from the Sun.

Directing his telescope on the planets, Galileo discovered that, unlike the stars, which remained pointlike in his telescope, the planets appeared like small disks, or, in the case of Venus, as a miniature crescent. This convinced him that the stars are much farther away from Earth than the planets. He also discovered that the Milky Way consists of a large number of stars.

Observing Jupiter, Galileo discovered that it is surrounded by four "stars" (at that time planets, as well as fixed stars, were just called stars). He called these natural satellites or moons, as we now know them to be, Medicean stars in honor of the Medici, rulers of Florence. He started observing their motion around Jupiter and came to the conclusion that they must be circling the planet in the same way as the Moon orbits Earth. This discovery was an important one because it showed that the Earth-Moon system is not a unique anomaly, which many people thought an important objection to the Copernican system.

The strongest proof for the validity of the Copernican system came from Galileo's observations of the phases of Venus. Not only did it become clear that Venus reflects light from the Sun and does not shine by its own light, but also that the size of Venus changes with the changes of its phase. When the planet was visible as a complete disk, it was very small, and when it became a narrow crescent, its apparent diameter became large. This could only be explained by assuming that the planet orbits the Sun.

Finally, by observing the motion of sunspots, Galileo demonstrated the rotation of the Sun.

GALILEO'S FIRST TELESCOPE When news of the first telescopes reached Italy, Galileo immediately constructed his own three-power version in June or July 1609. Rapidly improving the instrument, he presented an eight-power telescope to the Venetian Senate in August, and began to make his famous astronomical discoveries with a twenty-power instrument in October or November of the same year.



Energy

The first attempt is made to harness the tides in the Bay of Fundy as a source of power. Small mills are successfully powered by this means.

Tools

Hans Lippershey and, separately, Zacharias Janssen invent the compound microscope. Janssen may have done so as early as 1590. See also 1590 TOOL.

1610

Astronomy

Galileo turns his telescope to the night skies and sees the four largest moons of Jupiter on January 7, Saturn's rings (which he does not understand), the individual stars of the Milky Way, and the phases of Venus. He also discovers that the Moon has geographic features like those of Earth—mountains and what he mistakenly thinks are seas. He reports this in *Sidereus nuncius* ("starry messenger"), a series of newsletters that make him famous all over Europe. See also 1609 AST; 1679 AST.

Sidereus nuncius ("starry messenger"), a series of newsletters that make him famous all over Europe. See also 1609 AST; 1679 AST.

Chemistry

Tyrcinum chymicum by Jean Beguin [b. Lorraine, France, c. 1550, d. Paris, c. 1620] is the first textbook on chemistry instead of alchemy.

Food & agriculture

The first tea from Asia arrives in Europe.

Tools

Cornelius Drebbel designs temperature regulators to control the temperature of an oven for chemical experiments and to control an incubator.

The basic modern arrangement for a compound microscope, in which both lenses are convex and the resulting image is inverted, is developed by Kepler. See also 1609 TOOL; 1673 TOOL.

Saturn's rings

In 1610, Galileo reported to Johannes Kepler:
“SMAISMRRMILMEPOETALEMIBUNENUGTTAUIRAS”

This report of a major new discovery with the new telescope was an anagram, a scrambled message. Anagrams were used in the 17th century to establish the priority of a discovery without revealing what had been discovered. (Imagine Watson and Crick sending a colleague an anagram of “DNA IS DOUBLE HELIX.”) In this case, Galileo eventually unscrambled the anagram as ALTISSIMUM PLANETAM TERGEMINUM OBSERVAVI, or (loosely) “I have observed the most distant of planets to have a triple form.” Note that U and V were considered interchangeable in Latin. This meant that Galileo had found that Saturn appeared to have two satellites.

What Galileo saw was harder to interpret than that, however. In his notebook, the drawing of Saturn looks like a ball with handles. To make matters more complicated, three years later the “handles” had disappeared. Galileo asked, “Has Saturn perhaps devoured his own children?” But by 1616 the planet once again showed its odd triple shape.

Using a better telescope, Christiaan Huygens was able in 1656 to write an anagram announcing that Saturn has a ring. Huygens, however, assumed that the ring is a single, solid structure. Giovanni Cassini observed in 1675 that there were at least two rings separated by a gap and correctly guessed that the rings are made up of many small objects. But Cassini’s view was not accepted until James Clerk Maxwell studied the problem mathematically in 1857, more than 200 years after Galileo had observed the rings for the first time.

1611

★ Astronomy

French astronomer Nicolas-Claude Fabri de Peiresc [b. Beaugensier, France, December 1, 1580, d. Aix-en-Provence, France, June 24, 1637] is the first astronomer to discover the Orion Nebula. *See also* 1619 AST.

German astronomer Christoph Scheiner [b. Wald, Rhine Province (Germany), July 25, 1575, d. Neisse, Silesia (Nysa, Poland), June 18, 1650] observes sunspots in March, prompting him into a controversy with Galileo as to who has seen them first. Thomas Harriot and Johannes Fabricius discover sunspots around the same time. Galileo claims to have seen a sunspot as early as 1607 but believed it to be the planet Mercury passing in front of the Sun. *See also* 1613 AST.

■ Construction

The 57-m (186-ft) Tour de Cordouan lighthouse at the mouth of the Garonne River in southern France, begun in 1584 and designed by Louis de

Foixe, is the first lighthouse to have a revolving beacon and the first to be built on rock in the open ocean; it was preceded by a simple tower with a lighted fire. *See also* 1304 CONS; 1698 CONS.

After religious wars cool down, two bridges started much earlier are completed in France: the Pont Henri IV, started in 1576, is completed at Châtellerault; the Pont Neuf of Toulouse (not to be confused with the Pont Neuf in Paris), designed by Jacques Le Mercier and started in 1542, is completed over the Garonne. The Pont Neuf of Toulouse uses elliptical arches with a maximum span of 32 m (104 ft). *See also* 1607 CONS; 1685 CONS.

■ Food & agriculture

Thomas Coryate [b. Somersetshire, England, c. 1577, d. Surat, India, 1617] writes *Crudities Hastily Gobbled Up in Five Months* about his travels in France, Italy, Switzerland, and Germany during 1608. In the book he advocates the use of the fork, a custom that he introduces about this time to

English society. *See also* 1533 FOOD; 1630 FOOD.

❖ Materials

Simon Sturtevant [b. Lincolnshire, England, 1570] obtains the first British patent in which coal is used instead of charcoal for smelting iron. The process does not become commercially successful for a hundred years. *See also* 1589 MATR; 1620 MATR.

❖ Physics

Yugoslav physicist and clergyman Marko Antonije de Dominis [b. Rab (Yugoslavia), 1566, d. in prison, Rome, September 8, 1626] publishes a scientific explanation of the rainbow. He is best known for his opposition to papal authority. *See also* 1514 PHY; 1637 EAR.

Kepler’s *A New Year’s Gift, or on the Six-Cornered Snowflake* contains the first detailed description of the hexagonal nature of snowflakes in the West, although this characteristic was known earlier in China and had been observed several years earlier by

Thomas Harriot. *See also* 1591 EAR.

■ Tools

Kepler in *Dioptrice* describes the so-called astronomical telescope with an inverting refractor. *See also* 1608 TOOL; 1663 AST.

1612

★ Astronomy

German astronomer Simon Marius (Mayr) [b. Gunzenhausen (Germany), January 20, 1573, d. Anspach, Bavaria, December 26, 1624] is the first astronomer to mention the Andromeda Galaxy. *See also* 1781 AST.

❖ Physics

Galileo’s *Discorso intorno alle cose che stanno in su l’acqua* (“discourse on things that float in water”) uses principles from Archimedes to develop elementary hydrostatics. *See also* 250 BCE MATH; 1628 CONS.

■ Tools

Sanctorius Sanctorius’s *Commentaria in artem medicinalem Galeni* (“commentary

on Galen's art of medicine") contains the first printed mention of the thermoscope, a primitive thermometer invented by Galileo. *See also* 1592 TOOL; 1641 TOOL.

1613

★ Astronomy

Galileo's *The Sunspot Letters* reports on his observations of sunspots. It is his first printed statement favoring the Copernican system, and it contains his first formulation of the principle of inertia. *See also* 1350 PHY.

Biology

Hortus eystettensis ("the garden of Eichstätt") by German pharmacist Basilius Besler [b. 1561, d. 1629], based on the gardens of the Prince Bishop of Eichstätt in Bavaria (Germany), is an important work in plant illustration.

Σ Mathematics

Pietro Cataldi's mathematics in *Trattato del modo brevisimo di trovar la radice quadra delli numeri* ("treatise on a short way to find the square roots of numbers") introduces more extensive use of continued fractions to Europe. Continued fractions, however, had previously been used by Indian mathematicians and by Rafael Bombelli. Continued fractions are those whose denominators contain fractions that also contain fractions in the denominator and so on for an infinite progression of fractions in the denominator. They are a convenient form for expressing many problems involving limits. *See also* 1572 MATH.

1614

□ Chemistry

The first chemical works by the European colonists in Jamestown (Virginia) is a salt-peter facility built to produce a key ingredient for gunpowder. *See also* 1585 MATR.

◊ Materials

Cementation steel (blister steel) is introduced. In cementation, carbon is placed into contact with iron at a high temperature, causing the carbon to penetrate into the iron and make it into steel.

Σ Mathematics

John Napier's *Mirifici logarithmorum canonis descripto* ("description of the wonderful canon of logarithms") explains the nature of logarithms and gives tables and rules for their use in computation. Logarithms today are recognized as the exponents

needed to raise a given base to a power equal to specific numbers. In Napier's original formulation, he developed logarithms of sines based on ratios (*logarithm* means "number of the ratio"). *See also* 1594 MATH; 1615 MATH.

♥ Medicine & health

Sanctorius Sanctorius's *Ars statica medicina* ("art of static medicine," where *static* means in balance) is the first study of metabolism. Sanctorius records measurements on himself of changes in weight, pulse, and temperature and expresses the results as a series of aphorisms.

1615

⊕ Earth science

English explorer William Baffin [b. England, c. 1584, d. Persian Gulf, January 23, 1622] penetrates to within 1300 km (800 mi) of the

North Pole, the closest any explorer will be until the 19th century.

Σ Mathematics

Kepler's *Nova stereometria doliorum vinariorum* ("new measurement of the volume of wine casks") uses infinitesimals to calculate the volume of various solids of revolution, such as wine casks — anticipating the integral calculus. *See also* 1635 MATH.

Marin Mersenne [b. Oizé, Maine, France, September 8, 1588, d. Paris, September 1, 1648] calls attention to the cycloid, the curve formed by the motion of a point on a circle as the circle is rolled along a line. The cycloid is called "the Helen of geometers" because it provokes so many quarrels among 17th-century mathematicians who are investigating its properties. *See also* 1634 MATH.



MODEL OF A CYCLOID This wooden model shows a track shaped in the famous curve known as a cycloid. One of several alternate names for the cycloid, the isochrone ("same time") is illustrated by the model — an object placed anywhere on the track will slide to the bottom in the same amount of time as an object placed at a different point on the track. This property was exploited by Christiaan Huygens — who discovered it — to create a pendulum that, because its weight is constrained to fall in a cycloidal path instead of an arc of a circle, will have exactly the same period for any amplitude.

Henry Briggs [b. Warleywood, Yorkshire, England, February 1561, d. Oxford, England, January 26, 1630] proposes to John Napier that logarithms be developed using ten as a base for ease in calculations. Known either as common logarithms or Briggsian logarithms, these become the common form used in calculations until the advent of the hand-held calculator and computer. Natural logarithms, still used extensively in mathematics, have a base of e , a number with an infinite decimal expansion but equal approximately to 2.7. See also 1614 MATH; 1617 MATH.

I Tools

Salomon de Caus [b. Normandy, France, 1576, d. Paris, 1626] describes a steam pressure ball for ejecting water under steam pressure in *Les raisons des forces mouvantes* ("about violent forces"). He also gives a description of a rolling mill and describes a number of automatons. De Caus had built some of these moving figures for the garden of Heidelberg Palace and later, on a greater scale, for the Duke of Burgundy's palace near Paris. See also 1629 ENER.

1616

★ Astronomy

Galileo receives a warning from Cardinal Robert Bellarmine that he should not hold to or defend the Copernican doctrine that Earth revolves about the Sun. Copernicus's *De revolutionibus* is placed on the *Index librorum prohibitorum* of the church, from which it will not be removed until 1835. See also 1632 AST.

⊕ Earth science

Galileo, hoping to win a prize and pension set up by Philip III of Spain for anyone who can find the longitude at sea, suggests using the satellites of Jupiter. Although ignored by Philip, Galileo's method will later be used to find accurate longitudes on land. See also 1598 TRAN; 1714 TRAN.

◊ Materials

Porcelain pottery is made in Japan after a deposit of kaolin is found on Kyushu by imported Korean potters. See also 1150 MATR.

♥ Medicine & health

William Harvey lectures about the circulation of blood to the Royal College of Physicians. See also 1559 MED; 1628 MED.

1617

▀ Computers

John Napier in *Rabdologia* describes the mechanical device for multiplying that comes to be known as Napier's rods or Napier's bones. It can be used by moving several rods to show a pair of factors; the product then can be read from other numbers on the rods. See also 1620 COMP.

Σ Mathematics

Eratosthenes batavus ("the Batavian Eratosthenes") by Willebrord van Rijen Snell [b. Leiden, Holland (Netherlands), 1580, d. Leiden, October 30, 1626] develops the method of determining distances by trigonometric triangulation. He shows how to measure the distance between two cities in Batavia (region of Netherlands), as Eratosthenes used triangles to measure Earth's circumference. See also 1595 MATH.

Logarithmorum chilias prima ("logarithms of numbers from 1 to 1000") by Henry Briggs introduces common logarithms. See also 1615 MATH; 1619 MATH.

1619

★ Astronomy

Swiss astronomer Johann Cysat [b. Lucerne (Switzerland), 1586, d. Lucerne, May 3, 1657] surveys the sky, in the process rediscovering the Orion Nebula. See also 1611 AST; 1656 AST.

Kepler's *Harmonice mundi* contains his third law of planetary motion (that the squares of times of revolution of any two planets are proportional to the cubes of their mean distances from the Sun) and his theories

of harmonies in nature. See also 1609 AST; 1626 AST.

Kepler's *Epitome astronomiae Copernicanae* ("summary of Copernican astronomy") is a defense of the Copernican system in three parts (the last published in 1621) and is immediately put in the *Index librorum prohibitorum* of the Roman Church. See also 1616 AST.

Kepler explains that a comet's tail points away from the Sun as a result of what we now call the solar wind — particles from the Sun that push material from the comet out of the head and away from the Sun. See also 1540 AST.

↗ Biology

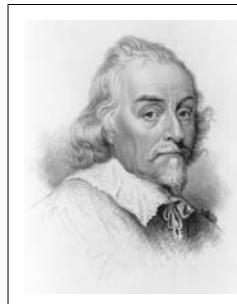
Lucilio Vanini [b. Italy, 1584, d. 1619] is burned alive at the stake for his proposal that humans evolved from apes. See also 1860 BIO.

↳ Communication

René Descartes experiences a famous dream on November 10 in which he is given the message that he should work out the unity of the sciences on a purely rational basis.

Σ Mathematics

John Speidell publishes logarithms of trigonometric functions in *New Logarithmes*. See also 1596 MATH.



William Harvey

[b. Folkestone, England, April 1, 1578, d. London or Roehampton, Surrey, June 3, 1657]

Harvey was the first to propose that the heart is a pumping organ that propels blood on a circular course through the body, leaving through arteries and returning to the heart through veins. He noted that blood spurts from a cut artery in conformity with muscular contractions of the heart, and observed that clamping a vein causes it to swell with blood on the side away from the heart.



René Descartes

[b. La Haye, France, March 31, 1596, d. Stockholm, Sweden, February 11, 1650]

The philosopher Descartes was the first to publish a detailed account of how to use coordinates for locating points in space, called analytic geometry, although Fermat developed the concept slightly earlier. In an appendix to his book *Discours de la méthode* Descartes gave analytic geometry to the world and used the new technique to solve problems in geometry. Analytic geometry made calculus and many other advances in mathematics possible. Descartes also developed (incorrect) theories of how the planets move and obtained important (correct) results in optics. His emphasis on rational thought was important in creating modern science.

1620

Communication

Francis Bacon's *Novum organum* ("new organon," referring to Aristotle's book on logic, the *Organon*) recommends induction and experimentation as the basis of the scientific method. *See also* 1605 COMM; 1626 COMM.

Computers

Edmund Gunter [b. Hertfordshire, England, 1581, d. London, December 10, 1626] cre-

ates a device similar to a slide rule by locking Napier's bones on a surface. *See also* 1617 COMP; 1621 COMP.

Materials

The first beehive ovens for making coke are introduced in England. Although inefficient, they are cheap to manufacture. *See also* 1611 MATR; 1841 MATR.

Mathematics

Arithmetische und geometrische progress-tabulen

by Joost Bürgi [b. Lichtenstein, February 28, 1552, d. Kassel (Germany), January 31, 1632] contains an independent discovery of logarithms. *See also* 1614 MATH.

Physics

Jan (Johannes) Baptista van Helmont [b. Brussels (Belgium), January 12, 1580, d. Vilvoorde, near Brussels, December 30, 1644] coins the term "gas" to describe substances that are like air. The word *gas* is his own peculiar

spelling of the Flemish word for chaos.

Transportation

Cornelius Drebbel builds a navigable submarine that can carry 24 persons. Powered by rowers it cruises 5 m (15 ft) below the surface of the Thames in London on several occasions. The ability of the craft to stay submerged is probably enhanced by the production of oxygen from saltpeter by a process Drebbel keeps secret. *See also* 1535 TRAN; 1716 TRAN.

1621

Biology

Hieronymus Fabricius's *De formatione ovi et pulli* ("on the development of eggs and chickens"), published posthumously, elevates embryology to the level of a science. *See also* 1651 BIO.

Francis Bacon and the scientific method

Francis Bacon is one of the important thinkers of the Scientific Revolution of the 17th century. Although Bacon was neither a mathematician nor an experimental scientist, he exerted great influence on his contemporaries by introducing a method in which science is based on observation and experimentation.

He argued that the sciences should follow the example of the "mechanical arts" by being "founded on nature." But he also asserted that the mechanical arts should have science as their master. Bacon was one of the first thinkers to bridge the gap that existed between technology and the sciences. Since antiquity, technical invention was unrelated to science; it was the domain of the artisan. Artisans built machines based on empirical experience only. Science was thought to deal with ideas only. Bacon strongly opposed this concept and asserted that the knowledge of practical things also belongs to science. Because Bacon was not a scientist himself (although he died from a cold

caught while stuffing a chicken with snow in an experiment with refrigeration), he extended his ideas on science to every aspect of human life. In Bacon's view, science not only serves to fulfill our intellectual curiosity, but it is also useful in all phases of humanity.

Bacon was one of the first to fully understand that knowledge is power. He believed science would serve to improve the human condition and create a better world, and stated that the final goal of science is "the relief of man's estate" and the "effecting of all things possible."

Bacon described a model of such a better world in his book *New Atlantis*. New Atlantis is an island with a utopian society whose well-being is entirely based on science and technology. In his book Bacon gave his contemporaries an extraordinary look into the future of technology. He mentions the skyscraper ("High Towers, the Highest about half a Mile in height"), the refrigeration of food, air-conditioning ("Chambers of Health, wher wee qualifie the Aire"), telephones ("meanes to convey Sounds in Trunks and Pipes"), airplanes, and submarines.

■ Computers

About this time William Oughtred [b. Eton, England, March 5, 1574, d. Albury, Surrey, England, June 30, 1660] invents the slide rule (according to Oughtred's statement in 1632). *See also* 1620 COMP; 1623 COMP.

■ Food & agriculture

Pilgrim settlers in Massachusetts observe that Native Americans bury a dead fish in each hill of maize (corn) planted to ensure a good yield. *See also* 1699 FOOD.

◆ Materials

Lead mining begins in the United States.

Lord Dudley obtains a patent for a method of making iron using coal instead of charcoal. The method is invented by his natural son Dud Dudley [b. Worcestershire, England, 1599, d. Worcester, October 25, 1684]. *See also* 1611 MATR; 1665 MATR.

Σ Mathematics

The famous edition of Diophantus's *Arithmetica* ("arithmetic") is published in Greek with a Latin translation, launching the revival of number theory; it is best known for having too narrow a margin to accommodate Fermat's "last theorem." *See also* 1637 MATH.

✿ Physics

Willebrord Snell discovers that refraction of light is determined by the sine of the angle made by the incident ray (Snell's law). *See also* 1637 PHY.

I Tools

An improved ribbon loom is developed. *See also* 1604 TOOL.

1622

⌚ Communication

The first German scientific academy, the Societas Ereunitica, is founded at Rostock.

🌐 Earth science

Edmund Gunter discovers that magnetic declination varies with time. *See also* 1600 EAR.

1623

☒ Biology

Pinax theatri botanici by an anatomist Gaspard Bauhin, [b. Basel, Switzerland, January 17, 1560, d. Basel, December 5, 1624] introduces the practice of using binomial names, one for the genus and a second for the species. *See also* 1735 BIO.

⌚ Communication

The Statute of Monopolies, which lays down the laws for granting patents (that is, monopolies limited to a period of time) for inventions, is passed in England. Previously, the king had granted monopolies; subsequent efforts through the reign of Charles I to reassert the king's powers in this matter are finally and definitely overcome by the Long Parliament in 1640. *See also* 1474 COMM; 1790 CONS.

■ Computers

In Tübingen (Germany) astronomer Wilhelm Schickard (Schickardt) [b. Herrenberg (Germany), April 22, 1592, d. Tübingen, October 23, 1635] builds a mechanical calculator based on the ideas of Napier's bones. The machine can add, subtract, multiply, and divide and is

intended to aid astronomical calculations. A copy is planned for Kepler, but not completed as a result of the Thirty Years' War, which also results in the loss of Schickard's calculator. Discovery of a description in 1957 of the Kepler model leads to construction of a working copy. *See also* 1617 COMP; 1957 COMP.

1624

Σ Mathematics

Henry Briggs's *Arithmetica logarithmica* ("the arithmetic of logarithms") extends his tables of common logarithms to numbers from 1 to 20,000 and from 90,000 to 100,000. The book also introduces Latin forms of the words *mantissa* and *characteristic*. *See also* 1619 MATH.

1625

☽ Chemistry

Johann Rudolf Glauber [b. Karlstadt (Germany), 1604, d. Amsterdam (Netherlands), March 10, 1670] discovers Glauber's salt (crystalline sodium sulfate) around this time. Believing in its power to cure wounds, Glauber called it *sal mirabile* ("wonder salt"). *See also* 1602 CHEM.

I Tools

The snap-haunce lock, predecessor of the flintlock, is introduced as a way of firing guns. Like the flintlock, the snap-haunce creates a spark by mechanically striking flint and steel when a trigger is pulled. The flintlock is based on the same idea, but parts are arranged for more efficient

and reliable operation. *See also* 1515 TOOL; 1700 TOOL.

1626

★ Astronomy

Godfried Wendelin (Vendelinus) [b. Herck la Ville, Belgium, June 6, 1580, d. Ghent (Belgium), 1667] shows that Kepler's laws are valid for the moons of Jupiter. *See also* 1619 AST.

⌚ Communication

Francis Bacon, English philosopher, dies in London on April 9, a month after performing his first scientific experiment — stuffing a chicken with snow to see if it will decay less rapidly. The chill he catches during this experiment is thought to lead directly to his death. *See also* 1620 COMM; 1627 COMM.

■ Construction

St. Peter's Church in Rome, originally designed by Bramante and redesigned by Michelangelo, is finally consecrated more than a hundred years after Michelangelo's death. It will be the largest church in the world for more than 250 years. *See also* 1590 CONS; 1990 CONS.

♥ Medicine & health

Jan Baptista van Helmont proposes that diseases are caused by alien beings called "archaeae."

I Tools

Pappenheim, a German inventor, sketches a design for a rotary pump. It is first used in Watt's early steam engines and still used as a fuel pump in Wankel-engine automobiles.



ST. PETER'S OF ROME, THE PIAZZA, AND THE OBELISK The greatest architects of the time designed St. Peter's and the piazza before it: Caradoso, Bramante, della Porta, Michelangelo, Raphael, Sangallo, and Bernini all had a hand in making what was for many decades the largest Christian church and its environs.

1627

★ Astronomy

Kepler's *Rudolphine Tables* contain the locations of 1005 stars, 777 of which come from Tycho's previous catalog, and calculation of the motions of the planets. *See also* 1602 AST.

Ⓑ Biology

The aurochs, a wild ancestor of domestic cattle, becomes extinct, with the last known creatures in Europe, although the large animal previously also roamed over western Asia and northern Africa.

Ⓒ Communication

Francis Bacon's *The New Atlantis*, published posthumously, is a utopian tale that predicts robots, telephones,

tape recorders, and the electric motor, while emphasizing the importance of experiment over deduction. *See also* 1620 COMM.

◊ Materials

Mathurin Jousse [b. c. 1575, d. 1645] publishes his *Théâtre de l'art du charpentier*, in which he discusses certain properties of materials, thus being an early precursor of materials science. *See also* 1593 MATR.

1628

■ Construction

Physicist Benedetto Castelli [b. Perugia (Italy), 1577, d. Rome, April 19, 1643], one-time student of Galileo and later superintendent of waters

in the region around Bologna and Ferrara, publishes *Della misura dell'acque correnti* ("on the measurement of running waters"), the foundation of hydraulic technology. *See also* 1612 PHY.

♥ Medicine & health

William Harvey's *Exercitatio anatomica de motu cordis et sanguinis in animalibus* ("anatomical treatise on the movement of the heart and blood in animals") describes his discovery of the circulation of blood. *See also* 1616 MED.

1629

↗ Energy

Engineer and architect Giovanni Branca [b. 1571, d.

1640] describes in his machine book *Le machine a steam turbine* in which steam is directed at vanes on a wheel. *See also* 1582 ENER; 1663 ENER.

■ Food & agriculture

Jan Andriaanszoon (Leeghwater) proposes draining the Haarlemmermeer in Holland, using 160 of his multistaged water lifts, but the cost of 3,600,000 guilders is too great for the plan to be financed. The Haarlemmermeer is not drained until 1852. Andriaanszoon is hired by the Duc d'Eperven to drain the marshes of Gironde. *See also* 1608 FOOD.

Σ Mathematics

Pierre de Fermat reconstructs

the lost *plane loci* of Apollonius and, in the process, begins to develop the ideas that will lead to the invention of analytic geometry by the spring of 1636.

L'invention nouvelle en l'algèbre “the new invention in algebra”) by Albert Girard [b. St. Mihiel, France, 1595, d. Leiden (Netherlands), December 8, 1632] asserts but does not prove a version of the fundamental theorem of algebra: Every equation of algebra has as many solutions as the exponent of the highest term. This theorem will be correctly proved for the first time by Karl Friederich Gauss in 1799. *See also* 1799 MATH.

1630

★ Astronomy

Galileo determines that the star Vega has an angular diameter of less than 2 arc seconds by hanging a thin cord between him and the star and observing that the star can be hidden by the cord.



Pierre de Fermat

[b. Beaumont-de-Lomagne, France, August 20, 1601, d. Castres, near Toulouse, France, January 12, 1665]

Fermat was a lawyer whose thoughts on mathematics were transmitted mainly by correspondence with other mathematicians. He discovered analytic geometry a year before Descartes had the same idea. Fermat employed some of the main ideas of calculus before either Newton or Leibniz. His main fame today, however, comes from his work in number theory. Fermat's “last theorem,” which is that for natural numbers x , y , and z there is no natural number n greater than 2 for which $x^n + y^n = z^n$ is true, is especially well known. Fermat claimed a proof of this theorem, but did not reveal it. It was finally proved in 1995.

॥ Food & agriculture

The first dining fork in the Massachusetts Bay Colony and possibly the only fork in North America is imported by Governor John Winthrop. *See also* 1533 FOOD.

Johann Glauber proposes the use of saltpeter as a fertilizer. *See also* 1621 FOOD; 1699 FOOD.

※ Physics

Father Cabaeus, a Jesuit priest, notices that electrically charged bodies first attract each other and then repel each other after contact. *See also* 1600 EAR; 1650 ENER.

→ Transportation

Wooden rails are installed in the coal mines of Newcastle, England, for coal carts to travel on.

1631

★ Astronomy

Pierre Gassendi [b. Provence, France, January 22, 1592, d. Paris, October 24, 1655], using calculations made by Kepler, becomes the first to observe a transit of Mercury across the face of the Sun. *See also* 1639 AST.

Σ Mathematics

Thomas Harriot's *Artis analyticiae praxis* (“practice of the analytic art”), printed posthumously, uses AAA to mean the cube of A and similar old-fashioned notations for other powers, but symbolizes multiplication with a centered dot and introduces $<$ and $>$ for “is less than” and “is greater than,” modern notations. *See also* 1591 MATH.

William Oughtred's *Clavis mathematicae* (“key to mathematics”) introduces many new notations, of which only \times for multiplication continues in use today. *See also* 1557 MATH.

Circulation of the blood

It seems obvious today that blood is pumped through the body by the heart. Also, anyone with the slightest acquaintance with anatomy has learned that blood also passes from the heart to the lungs and back before making its trip through the body. But this was far from obvious to early physicians and scientists.

There were several obstacles. Among them, blood drains from cut arteries and veins in cadavers, making it difficult to observe the purpose of these tubes. In Antiquity dissection revealed that the tubes we call arteries pass from the lungs, so a common misconception was that in life the tubes carry air from the lungs around the body — not far from the truth that they carry oxygen dissolved in blood, but also quite misleading. A view somewhat

closer to the truth was that the arteries carry “animal spirits” derived from air in the lungs. Galen, about 170 CE, finally established that the arteries carry blood and not air.

Chinese physicians believed from very early in their history that blood circulates throughout the body. In the 16th century, some writers, notably Michael Servetus and Realdo Colombo, guessed or observed the circulation of the blood, but failed to convince many. William Harvey seems to have concluded the truth about blood circulation as early as 1616 and published a complete description of circulation in 1628.

Even though Harvey convinced many physicians of his conclusion, there were various unresolved problems. For one thing, no one knew in 1628 how blood could travel from the arteries to the veins. Studies with the microscope finally resolved that problem when Marcello Malpighi discovered capillaries in 1660.

The Church and astronomy

Galileo's first clash with members of the Catholic Church was caused by a question of priority. Sunspots were observed by the Jesuit priest Christoph Scheiner, but in 1613 Galileo claimed to have discovered sunspots before Scheiner. His conflict with Scheiner had no immediate consequences, but caused problems later.

In letters Galileo argued that not everything in the Bible should be taken literally. Galileo further argued that the church had the burden of proving that the Copernican system is wrong. The Dominicans obtained copies of the letters and forwarded them to the Holy Office in Rome along with Galileo's book *The Sunspot Letters*, in which he showed his support of Copernican views.

In December 1615, Galileo traveled to Rome to defend his opinions. In February 1616, the Inquisition declared that the opinion that the Sun is the center of the world is heretical and

decreed that the works of Copernicus be withdrawn until corrected. Galileo was admonished to cease defending the Copernican system.

Galileo lived in relative peace with the church until the publication in 1632 of his *Dialogue concerning the Two Chief World Systems, the Ptolemaic and the Copernican*. The book consists of a dialogue among a convinced Copernican, a stupid anti-Copernican, and an impartial commentator. Scheiner, Galileo's enemy since the dispute over sunspots, convinced Pope Urban VIII that Galileo had intended to portray him as the stupid anti-Copernican. Furthermore, the "impartial" commentator appeared to be pro-Copernican also. The pope summoned Galileo to appear before the Inquisition in 1633. Galileo was sentenced to abjure the Copernican doctrine, which he did; he was put under house arrest.

The Catholic Church continued officially to deny the Copernican theory until 1922.

I Tools

Engineer Pierre Vernier [b. Ornans, France, August 19, 1580, d. Ornans, September 14, 1638] describes his invention for precision measurement, known today as the Vernier scale. Instead of a pointer moving along a scale, he uses a mobile scale with nine divisions that occupies the space of ten divisions on the main scale. The division on the mobile scale that coincides with a next division on the main scale indicates the number of tenths of one division on the main scale that have to be added. See also 1540 TOOL.

1632

★ Astronomy

Galileo's *Dialogo sopra i due massimi sistemi del mondo, Tolemaico e Copernico* ("dialogue concerning the two chief world systems, Ptolemaic and Copernican") puts him in disfavor with the pope and the book is banned. The "impartial" Salviati clearly

represents Galileo's own, pro-Copernican position. See also 1616 AST; 1633 AST.

Σ Mathematics

In *Dialogue Concerning the Two Chief World Systems* Galileo notes that the number of perfect squares is as large as the number of roots of perfect squares, the first known matching of a set with a proper subset of itself. This kind of matching eventually becomes a popular defining test for an infinite set. See also 1888 MATH.

❀ Physics

Galileo's *Dialogue Concerning the Two Chief World Systems* introduces relativity to physics by pointing out that physics experiments made in a closed cabin on a ship could not be used to tell whether the ship is moving or stationary.

1633

★ Astronomy

The Roman Catholic Inquisi-

tion forces Galileo to recant his Copernican views. Since 1761 tradition has held that at the end of his recantation he was heard to mutter *E pur se muove* ("nevertheless, it moves"). See also 1632 AST.

1634

⊕ Earth science

English astronomer and mathematician Henry Gellibrand [b. London, November 17, 1597, d. London, February 16, 1636] discovers that magnetic north (the direction to which a compass points) changes slowly. See also 1600 EAR.

Σ Mathematics

Giles Personne de Roberval [b. Roberval, France, August 1, 1602, d. Paris, 1675] proves that the area under a curve described by the motion of a point on a circle as the circle is rolled along a line for one circumference is exactly three times the area of the circle. The curve described by the

point is the famous cycloid. See also 1615 MATH.

1635

Σ Mathematics

Geometria indivisibilibus continuorum ("geometry of continuous indivisibles") by mathematician Bonaventura Cavalieri [b. Milan (Italy), 1598, d. Bologna (Italy), November 30, 1647] develops his method of calculating volumes by using infinitely small sections, an important precursor of the integral calculus. See also 1615 MATH.

Around this date, René Descartes discovers Euler's theorem that links the number of vertices, edges, and faces that a polyhedron topologically equivalent to a sphere must obey ($V - E + F = 2$). Since Descartes' discovery is not published until 1860, 108 years after Euler's rediscovery, the theorem is known as Euler's.

1636

Communication

Harvard College is founded.

Harmonie universelle ("universal harmony") by Marin Mersenne describes equal temperament in music for the first time in the West, although it was previously known in China. *See also* 1584 COMM; 1653 COMM.

Mathematics

Pierre de Fermat writes to Marin Mersenne that he has discovered the first pair of amicable numbers known since the single pair of 220 and 284 known to the ancient Greeks (amicable numbers are pairs such that the divisors of one number sum to the other number). Fermat's numbers are 17,296 and 18,416.

Fermat proposes in another letter to Mersenne that every natural number is the sum of at most three triangular numbers (stated publicly for the first time by Pascal in 1665 and finally proved in 1801 by Gauss). Triangular numbers are the sums of the consecutive counting numbers from 1 through a particular number, that is $1, 1+2=3, 1+2+3=6, 1+2+3+4=10$, and so forth. *See also* 1801 MATH.

1637

Astronomy

A permanent astronomical observatory is established at Copenhagen by King Christian IV of Denmark.

Communication

Descartes' *Discours de la méthode pour bien conduire le raisson et chercher la vérités dan les*

sciences

("discourse on the method of rightly conducting reason and seeking truth in the sciences") argues for use of the deductive method in science, illustrated by three famous appendices.

Earth science

In *Les météores*, an appendix to the *Discourse de la méthode*, Descartes explains the phenomenon of the rainbow and the formation of clouds. He reports on experiments with light refraction in water and proves mathematically that red light of a rainbow matches the angle of refraction it has in water. *See also* 1514 PHY.

Mathematics

Another appendix to Descartes' *Discours de la méthode*, *La géométrie*, contains the first published development of analytic geometry. This method of treating geometry with algebra was also developed in 1636 or earlier by Pierre de Fermat, but Fermat's work will not be published until 1670. *See also* 1636 MATH; 1692 MATH.

About this time Pierre de Fermat is thought to have written in the margin of a copy of the *Arithmetica* of Diophantus that an equation of the form $a^n + b^n = c^n$ can have no integral solutions for a, b , and c if n is greater than 2. His note continues, "I have found a truly marvelous demonstration which this margin is too narrow to contain." The statement has since come to be called Fermat's last theorem. *See also* 1676 MATH.

Physics

Descartes' *La dioptrique*, the third appendix to the *Discours de la méthode*, contains his

theory of refraction. *See also* 1621 PHY.

1638

Astronomy

Dutch astronomer Phocylides Holwarda identifies the first variable star, Mira Ceta, previously observed in 1596 by David Fabricus, who saw Mira gradually disappear. *See also* 1596 AST; 1669 AST.

Communication

Stephen Day installs the first printing press on the North American continent at Cambridge (Massachusetts).

Earth science

Galileo reports on experiments that among other results demonstrate that air has weight.

Materials

After the church forces him to withdraw from the study of the heavens, Galileo returns to an early interest in the strength of materials, which he treats along with other matters in *Discorsi e demonstrazioni matematiche intorno à due nuove scienze* ("mathematical discourses and demonstrations on two new sciences"). The book includes a study of the breaking strengths of beams that is flawed in parts, but extremely influential. *See also* 1594 TOOL.

Physics

Galileo's *Discorsi e demonstrazioni matematiche intorno à due nuove scienze* includes his mathematical discussion of the laws of motion and friction, in which he corrects many of Aristotle's errors. The book includes his experimen-

tal discovery that, ignoring air resistance, distance fallen increases with the square of the time.

1639

Astronomy

English astronomer Jeremiah Horrocks [b. Toxteth Park, near Liverpool, England, 1618, d. Toxteth Park, January 13, 1641] observes the transit of Venus on November 24, which he had predicted. The transit is the passage of the planet across the face of the Sun, which, because of slight differences in the angles of the orbits of Earth and Venus, occurs only twice each century. Horrocks is the first person known to have observed and reported the transit. *See also* 1631 AST; 1676 AST.

Materials

A glassworks is established in Plymouth (Massachusetts), one of the first manufacturing plants in the British colonies that will become the United States.

Mathematics

Brouillon projet d'une atteinte aux événements des rencontres d'un cone avec un plan ("rough draft of an attempt to deal with the meeting of a cone with a plane") by Gérard Desargues [b. Lyons, France, March 2, 1591, d. Lyons, 1661] gives birth to projective geometry, the mathematical study of geometric properties that remain invariant when a figure is transformed by projection from one plane to another.

French mathematician Florimond de Beaune [b. Blois, France, October 7, 1601, d. Blois, August 18, 1652] writes

Descartes to ask which curve has a constant subtangent (the distance from the place where the tangent meets the x axis and the point on that axis directly below where the tangent meets the curve). Descartes' reply fails to answer the question, but the exchange of letters later becomes known to Leibniz, who shows in 1684 that the solution is the logarithmic curve.

I Tools

William Gascoigne [b. Middleton, England, c. 1612, d. Marston Moor, Yorkshire, England, July 2, 1644] invents the micrometer about this time, placing it in the focus of a telescope for measuring the angular distance between stars. *See also* 1630 AST.

1640

S Mathematics

Essai pour les coniques ("essay on conics") by Blaise Pascal proves Pascal's theorem, also known as the mystic hexagram, which concerns the properties of a hexagon inscribed in a conic section.

Pierre de Fermat states in an October 19 letter to Bernard Frénicle de Bessy the "Little Theorem" of number theory: For any prime p and any nat-

ural number n , it is always true that p divides the difference of n raised to the power of p and n with no remainder.

* Physics

De motu gravium by Evangelista Torricelli applies Galileo's laws of motion to fluids, making Torricelli the father of hydrodynamics. *See also* 1612 PHY.

1641

↗ Biology

Physician Nicolaas Tulp [b. Amsterdam, Holland (Netherlands), October 11, 1593, d. The Hague, Holland (Netherlands), September 12, 1674] describes the first living chimpanzee brought to Holland.

♥ Medicine & health

Physician Franciscus Sylvius (Franz de le Boë) [b. Hanau, Prussia (Germany), March 15, 1614, d. Leiden, Holland (Netherlands), November 19, 1672] discovers the cleft separating the parietal, frontal, and temporal lobes of the brain. Today this is termed the Sylvian fissure, or the aqueduct of Sylvius.

I Tools

The son of Galileo, Vincenzo Galilei [b. Padua (Italy), 1606,

d. Florence (Italy), 1649], builds a clock with a pendulum, a device based on a concept of his father's. *See also* 1602 TOOL; 1656 TOOL.

1642

💻 Computers

Blaise Pascal develops a mechanical calculator that can add and subtract; he produces about 50 different versions of the calculator over the next ten years, some for sale, and also presents one to King Louis XIV. The calculator is sometimes known as the pascaline. The pascaline is a small brass box with, depending on the model, five to eight interlocking gears. The pascaline efficiently adds numbers and can also subtract, though less efficiently. *See also* 1623 COMP; 1645 TOOL.

↗ Transportation

The 55-km-long (34-mi-long) Briare Canal, started in 1605 by contractor Hugues Cosnier, linking the Loire and the Seine in France, is opened; a trip from one end to the other uses 40 locks. *See also* 1666 TRAN.

Evangelista Torricelli

[b. Faenza (Italy), October 15, 1608, d. Florence (Italy), October 25, 1647]

To investigate why vacuum pumps fail to raise water higher than about 10 m (30 ft), Torricelli, who suspected the answer, tried a heavier fluid. In 1643 he filled a long glass tube, closed at one end, with mercury, which is much denser than water, and placed the open end in a dish of mercury. When the tube was vertical, the mercury fell to about 76 cm (30 in.), forming a vacuum in the top of the tube. Torricelli correctly concluded that air pressure pushes on the mercury, lifting it. The vacuum prevents an equal push from the opposite direction. Torricelli also noted the small changes in height of the mercury related to changes in weather.

1643

I Tools

Evangelista Torricelli, on a suggestion from Galileo, develops the first barometer, using mercury as a fluid in a glass column sealed at the top. When the tube is upended in a dish, the mercury sinks to about 76 cm (30 in.), leaving a partial vacuum at the top. This also produces the first vacuum known to science. *See also* 1660 EAR.

1644

* Astronomy

Descartes' *Principia philosophiae* ("principles of philosophy") includes his vortex theory of the origin and state of the solar system, which he perceives in terms of whirling matter.



Blaise Pascal

[b. Auvergne, France, June 19, 1623, d. Paris, August 19, 1662]

Pascal's scientific contributions include the principle of hydrostatics, now known as Pascal's law, which is the basis of the hydraulic press used in hydraulic brakes and other applications. In mathematics, he helped found probability theory and did important work with infinite series and the geometry of curves. In 1640 Pascal began developing a machine that could help his father — a tax commissioner — calculate taxes. The first working model appeared in 1642. Known today as the pascaline, it was the first mechanical calculator that used gears. He also is considered a major French philosopher and author for his book *Pensées*.

The first vacuums on Earth

Aristotle concluded that a vacuum could not exist. He believed that an object would travel with infinite speed in a vacuum, but he did not believe an actual infinity could exist. Early scientists generally agreed that a vacuum could not exist in nature, but artisans proceeded to devise pumps that used the vacuum anyway. These pumps consisted of a cylinder tightly fitted in a tube. When the cylinder was raised, water flowed upward in the tube. The explanation of how such pumps worked, based on Aristotle, was that water had to rush into a tube as a cylinder was lifted because "nature abhors a vacuum!" If the water did not fill the empty space, the forbidden vacuum would be created.

Galileo learned from a workman that such vacuum pumps had a curious liability. They would not lift water more than about 10 m (30 ft). Galileo thought it odd that nature should abhor a vacuum for 10 m and then change its mind. He suggested that his assistant, Torricelli, investigate this matter. Torricelli soon realized that, contrary to Aristotle, a real vacuum might be created. Shortly after Galileo's death, Torricelli was able to produce a near vacuum with his mercury barometer. This was the first vacuum known to science, although it can be assumed that partial vacu-

ums were produced in water pumps by people trying to exceed the 10-m limit.

Pumps could not exceed this limit because their action depends on air pressure. Air pressure is strong enough to lift water 10 m when it is not opposed by anything. Above 10 m, a partial vacuum can exist because air pressure will not lift the water to fill it.

Interest in the vacuum continued through the second half of the 17th century. Otto von Guericke developed an air pump that could produce an impressive vacuum; he delighted in exhibitions of its power, demonstrating that it was more powerful than 50 men or two teams of horses. More important to science, he was able to show that sound could not travel in a vacuum, flames could not burn, and animals could not live. Boyle, who improved on Guericke's pump, demonstrated that a feather and a lump of lead fall at the same speed in a vacuum.

Production of a good vacuum, however, was difficult well into the 19th century. It was the ability to make a "hard" vacuum in a glass tube, achieved in 1854, that led to the discovery of X rays, the electron, and (indirectly) radioactivity. In the first half of the 20th century, vacuum tubes powered radio and television, computers, and other electronic devices, until they were largely displaced by solid-state devices, such as transistors and chips.

1645

★ Astronomy

Ismael Boulliau [b. Loudun, France, September 28, 1605, d. Paris, November 25, 1694] indicates in *Astronomia philosophoica* that the central force acting on planets must be proportional to the inverse square of the distance from the Sun (as will be proven later by Newton).

↳ Communication

Meetings of The Invisible College, precursor of the Royal Society, begin in London. Led by Sir Robert Moray [b. 1608, d. 1673], it counts Robert Boyle and Christopher Wren among the first members.

🍴 Food & agriculture

Sir Richard Weston, having observed crop rotation prac-

ticed successfully in Flanders, describes the concept to the English in the first written account of the method in Great Britain.

♥ Medicine & health

English physician Daniel Whistler [b. Elvington, England, 1619, d. 1684] gives the first medical description of rickets in his medical doctor's thesis at the University of Leiden (Netherlands).

☒ Tools

An early version of Blaise Pascal's adding and subtracting machine, the pascaline, goes on sale. See also 1642 COMP; 1652 COMP.

1646

↳ Communication

Athanasius Kircher [b. Geissa at

the Ulster (Germany), May 2, 1601, d. Rome, November 28, 1680] invents the magic lantern and describes it in his book on light and optics, *Ars magna lucis et umbrae* ("the great art of light and shadows").

↗ Transportation

Athanasius Kircher invents a distance-recording device, or milometer, for carriages.

1647

★ Astronomy

Johannes Hevelius's *Selenographia* is the first map of the side of the Moon observable from Earth.

Σ Mathematics

Bonaventura Cavalieri's *Exercitationes geometricae sex* ("six geometric exercises") demonstrates how to find the

integral of x^n (that is, the area under the curve described by x^n) for $n = 3, 4, 5, 6, 7, 8, 9$.

♥ Medicine & health

Jean Pecquet [b. Dieppe, France, May 9, 1622, d. Paris, February 1674] discovers the thoracic duct.

Yellow fever, brought along with slaves from Africa, strikes the island of Barbados in the Caribbean with the first recorded case in the Americas.

❀ Physics

Blaise Pascal's *Expériences nouvelles touchant le vide* ("new experiments with a vacuum") describes his experiments with vacuums produced above a column of water or red wine. See also 1643 TOOL; 1648 PHY.

1648

Biology

Jan Baptista van Helmont's *Ortus medicinae* ("on the development of medicine"), published posthumously, tells of his famous experiment of growing a willow tree and showing that its increase in weight does not come from the soil. The *Ortus medicinae* also contains many medical misinterpretations and mistakes.

Chemistry

Johann Rudolf Glauber discovers hydrochloric acid. *See also* 1625 CHEM; 1658 PHY.

Earth science

Semjon Deshnjov travels through the passage between America and Asia, proving that the two continents are not connected.

Mathematics

Desargues's theorem (if two triangles are placed so that lines joining pairs of corresponding vertices pass through a single point, then the points of intersection of pairs of corresponding sides are on a single line, and conversely) is published by his friend Abraham Bosse.

Mathematical Magik by John Wilkins [b. Fawsley, England, 1614, d. London, November 19, 1672] is an account of the fundamental principles of machines.

Physics

Blaise Pascal arranges for his brother-in-law to demonstrate that the height of the mercury column in a barometer is balanced by the pressure of air by carrying a barometer up the

mountain *Puy de Dôme*. *See also* 1643 tool

1649

Mathematics

Geometria a Renato Des Cartes ("geometry by René Descartes") by Frans van Schooten [b. Leiden, Holland (Netherlands), 1615, d. Leiden, May 29, 1660] translates into Latin and expands Descartes' *La géométrie*. In 1659–61 an expanded two-volume version will appear. This book introduces analytic geometry to scholars all over Europe.

Physics

Pierre Gassendi's study of Epicurus, *Syntagma philosophiae Epicuri*, asserts that matter is made up of atoms. *See also* 430 BCE PHY.

1650

Construction

The Taj Mahal, a tomb built for Mumtaz Mahal, who died in 1631, is complete. Built of white marble in front of a reflecting pool, it is considered among the most beautiful structures ever erected.

Energy

Otto von Guericke [b. Magdeburg (Germany), November 20, 1602, d. Hamburg (Germany), May 11 1686] demonstrates that electricity can be used to produce light, obtaining a luminous glow from a rotating globe of sulfur by applying pressure from his hand to the globe. *See also* 1630 PHY; 1703 ENER.

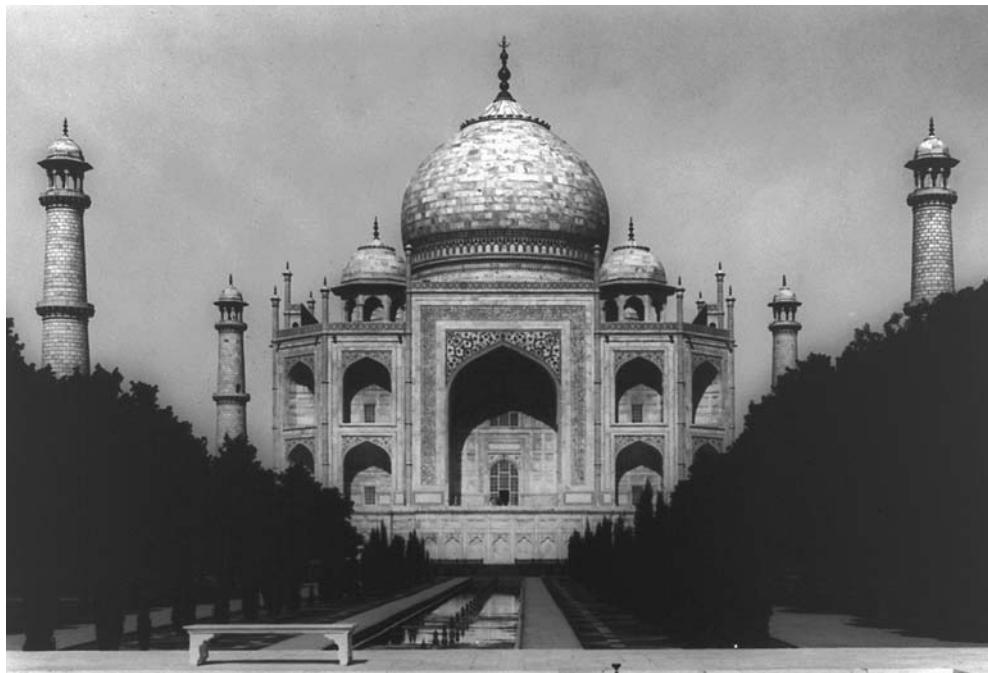
Medicine & health

De rachitide by Francis Glisson [b. Dorsetshire, England, 1597, d. London, October 14, 1677] gives a detailed clinical description of rickets.

About this time, according to legend, Franciscus Sylvius, while searching for a better diuretic, invents the drink gin — first called Genever or Geneva — essentially grain alcohol flavored with juniper berries.

Tools

Otto von Guericke perfects the air pump. He uses it to produce vacuums in experiments as early as 1645 and in public demonstrations in the 1650s and 1660s. The most famous demonstrations use teams of horses unable to break apart spheres held together by a vacuum. *See also* 1400 TOOL.



TAJ MAHAL Most photographs of this famous tomb show its whiteness and miss the details that are visible closer to the building. When visiting the Taj Mahal itself, however, the first view is the building reflected in the pool before it.

The advent of electricity

The Greeks and other ancient peoples knew that some substances attract others when one of them has been rubbed. Similarly, they must have encountered mild shocks. People still notice both today, as when clothing picks up lint without touching it or when a doorknob gives a slight shock on a dry winter's day. Thales, often counted as the first scientist, investigated the attractive properties of rubbed amber in Ionia around 600 BCE. He compared it to magnetism and noted that it was similar, but different. More than 2000 years later, around 1570, the English scientist William Gilbert also studied magnetism and the corresponding attraction of rubbed amber and various rubbed jewels. He modified the Greek and Latin terms for amber to produce the English word *electric* as a noun describing a material that behaved like amber. Nearly a hundred years later, in 1650, the term *electricity* was coined to refer to the force itself.

In the same year that *electricity* entered English, a German scientist, Otto von Guericke, was working with a method he had developed for making more electricity than could be made by rubbing a small piece of amber. He worked with a different electric, sulfur. He formed this electric into a ball, so it could be rubbed continuously by rotating it. Von Guericke was the first to observe light produced by electricity. Similar experiments produced light from electricity in England.

The electricity produced by von Guericke faded away soon after the ball stopped rotating. Shocks and lights were evanescent experiences. About a hundred years after the use of rotating balls, however, scientists in Leyden (Leiden, the Netherlands) learned that electricity could be stored in water in glass jars and conducted in and out with metal wires or nails. Modern versions

are somewhat different in construction, but the main impact of the Leiden jar was the same. A large charge could be stored up over time and then released by touching the conductor. Some terrific shocks resulted, and the jars became popular in parlors as well as with scientists.

Still, no one knew what electricity was. It was not even clear whether there was one type or two (different electrics attracted or repelled different light substances, although the shocks seemed to be the same). Accidentally, a scientist in Italy, Luigi Galvani, found that severed frogs' legs twitched in response to electricity and that they also responded the same way when touching metal that was not charged. Another Italian, Alessandro Volta, who had been experimenting with electricity, found that the reaction was chemical. He built an apparatus, which came to be known as the voltaic pile, that offered the first method of producing electricity in any quantity without rubbing. Improvements on the voltaic pile are the familiar batteries of today.

The main difference between electricity stored in a Leiden jar and that released by a battery is that chemically produced electricity does not all rush out at once. Instead, a steady flow like the current of a river appears. For the first time, electricity became available for periods of time, instead of instants.

Within 20 years, the next key event occurred, also by accident. Hans Christian Oersted discovered that the connection between electricity and magnetism, suspected since at least the time of Thales, was real. An electric current could produce magnetic effects. In another ten years the converse was shown, and magnets were being used to generate electric currents. With the development of powerful currents produced by magnetic generators, the stage was set for the use of electric power for light, for communication, and for production of motion.

➤ Transportation

Science fiction writer Cyrano de Bergerac [b. Paris, 1619, d. Paris, July 28, 1655] suggests seven ways of traveling from Earth to the Moon. Although six of the ways would not have worked, the seventh is by means of rocket. *See also* 1380 TRAN; 1680 TRAN.

1651

★ Astronomy

Almagestum novum by Giovanni Battista Riccioli [b. Ferrara (Italy), April 17, 1598, d. Bologna (Italy), June 25, 1671]

compares Tycho Brahe's model of the planetary system with the Copernican system and is in favor of the former because it is more in concordance with the Holy Scriptures. *See also* 1588 AST.

☒ Biology

William Harvey's *Exercitationes de generatione animalium* ("exercises on the generation of animals") describes organ differentiation in the developing embryo. He proposes that all organisms begin life as eggs. *See also* 1621 BIO.

1652

▷ Chemistry

Natural philosopher Elias Ashmole [b. Litchfield, England, May 23, 1617, d. London, May 18 or 19, 1692], the founder of the Ashmolean Museum in Oxford, publishes *Theatrum chymicum Britannicum*, a collection of works by various British chemists.

💻 Computers

Pascal's last version of his adding machine is exhibited in Paris. It is offered for sale at 100 livres, but that is a stiff

price for the day and few are sold. *See also* 1642 COMP.

♥ Medicine & health

Olof Rudbeck [b. Westerås, Sweden, December 12, 1630, d. Uppsala, Sweden, September 17, 1702] demonstrates his discovery of the lymphatic vessels to Queen Christiana of Sweden, using a dog.

De lacteis thoracis by Thomas Bartholin [b. Copenhagen, Denmark, October 20, 1616, d. Copenhagen, December 4, 1680] is a treatise on the lymphatic system describing the system in humans.

1653

Communication

Mathematician William Brouncker (formally William, 2nd Viscount Brouncker) [b. Castleyons, Ireland, 1620, d. Westminster, England, April 5, 1684] publishes a much enlarged translation of Descartes' pamphlet on music as *Renati Descartes musicae compendium* in which Brouncker proposes dividing the scale into 17 equal intervals, choosing 17 because of a relation to the golden ratio. *See also* 1636 COMM; 1701 PHY.

Food & agriculture

Dutch engineer Cornelius Vermuyden [b. Tholen (Netherlands), 1595, d. London, April 1683], commissioned by England's Charles I, succeeds in draining and reclaiming 124,000 hectares (307,000 acres) in the Fens region of England.

1654

Earth science

Irish scholar James Ussher [b. Dublin, Ireland, 1580, d. England, 1656], archbishop of Armagh, publishes his *Annales veteris et Novi Testamenti*, a work on biblical chronology that dates the Creation to 4004 BCE. This date will not be refuted until various lines of evidence in the 18th, 19th, and 20th centuries become available. *See also* 1907 EAR.

Mathematics

Blaise Pascal and Pierre de Fermat exchange letters about the basic laws of probability. They solve a problem of how to divide correctly the stakes in an interrupted game of

dice. The problem, proposed to Pascal by the Chevalier de Mérè, is first known from Fra Luca Pacioli (1494). It had been subsequently studied by Cardano and Tartaglia.

Pascal's *Traité du triangle arithmétique*, not published until 1665, contains his discoveries relating to the binomial coefficients, including what has come to be known as Pascal's triangle, although the triangle was known to many others previously, including Omar Khayyam. *See also* 1527 MATH.

Medicine & health

Francis Glisson's *Anatomia hepatis* gives a detailed anatomical description of the liver.

Tools

The Grand Duke of Tuscany, Ferdinand II [b. (Italy), July 14, 1610, d. May 24, 1670] invents a thermometer that uses liquid in a glass tube that has one end sealed; this is a slight improvement on Galileo's thermoscope; improvements on this basic design by Fahrenheit about 60 years later will result in the modern thermometer. *See also* 1592 TOOL; 1709 TOOL.

1655

Mathematics

Arithmetica infinitorum ("arithmetic of infinitesimals") by John Wallis [b. Ashford, England, December 3, 1616, d. Oxford, England, November 8, 1703] is an arithmetic treatment of infinite series and a step toward the integral calculus. Shortly before this, William Brouncker had proposed to Wallis a continued fraction that gives the value of $\pi/4$, which Wallis publishes as part of *Arithmetica infinitorum*.

Medicine & health

Johann Shultes's *Armamentarium chirurgicum* ("the hardware of the surgeon") describes a procedure for removing a female breast. *See also* 1545 MED.

1656

Astronomy

Christiaan Huygens discovers that the odd "handles" Galileo had seen on Saturn are really rings; he also discovers Saturn's largest satellite, Titan, and observes dark patches in the Orion Nebula, for which he is often credited with the discovery of the nebula, although it had been observed at least twice before. *See also* 1619 AST.



Christiaan Huygens

[b. The Hague, Holland, April 14, 1629, d. The Hague, June 8, 1695]

Huygens's first fame was as an astronomer. In the 1650s, using a refracting telescope he built himself, Huygens explored the Orion Nebula; discovered Saturn's largest moon, Titan; correctly identified the rings of Saturn; and made the first map of the planet Mars, enabling him to determine the planet's size and period of rotation. In physics, Huygens studied pendulums, making the first practical pendulum clocks, and the nature of light. In 1678, Huygens presented his wave theory of light, saying light behaves much like an ocean wave moving through the sea. Later work by Thomas Young confirmed that light acts as a wave.

Mathematics

John Wallis refers to mathematical induction as reasoning *per modum inductionis*, the first step toward naming the still new method of proof. *See also* 1575 MATH.

As part of his development of the pendulum clock, Christiaan Huygens discovers that the involute of a cycloid is a cycloid and that the cycloid is the curve required to make a pendulum strictly regular at all amplitudes. The involute of a curve is a second curve related to the first, based on the curvatures of the two curves.

Medicine & health

Adenographia, or a Description of the Glands of the Whole of the Body by Thomas Wharton [b. Winston-on-Tees, England, August 31, 1614, d. London, November 15, 1673] includes the first description of the submaxillary gland.

Tools

Christiaan Huygens develops a form of pendulum clock based on the cycloid. The cycloid is a curve that, when used to control a pendulum on a string, adjusts the beat precisely as the amplitude changes so that it remains the same; otherwise, the beat is only approximately steady. Despite the theoretical advantages of using a cycloid as a control, simpler forms of the pendulum clock will prove to be more practical. *See also* 1641 TOOL; 1673 TOOL.

1657

Communication

Leopoldo de Medici [b. Florence (Italy), 1617, d. 1675] founds the Accademia del

Cimento in Florence. It is the first scientific research institute since the Museum at Alexandria, which was destroyed in 641 CE. *See also* 1603 COMM; 1731 COMM.

Σ Mathematics

Christiaan Huygens's *De ratiociniis in ludo aleae* ("on reasoning in games of chance") is the first published work on probability. It introduces the concept of mathematical expectation. *See also* 1654 MATH; 1683 MATH.

William Neil [b. England, December 7, 1637, d. August 24, 1670] finds a way to determine the length of the semi-cubical parabola, which is the graph of $ay^2 = x^3$.

Fermat proposes the problem of finding the solution to $nx^2 + 1 = y^2$, an equation that, unknown to Fermat, had been studied at least as early as Brahmagupta in 628 CE and Bhaskara II in 1150. William Brouncker in an exchange of letters with Fermat and other mathematicians working on the problem finds a solution using continued fractions. The famous equation later comes to be known as Pell's equation, although John Pell [b. Southwick, England, March 1, 1611, d. London, December 12, 1685] had little or nothing to do with it.

♥ Medicine & health

Samuel Stockhausen, a physician in the mining town of Goslar in Germany, publishes about this time his explanation of a disease that is striking local mine and smelter workers. In the first study of an occupational disease, he identifies lead as the cause. *See also* 1697 MED.

I Tools

Dutch clockmaker Salomon Coster in The Hague begins to construct a series of spring-driven clocks that use a pendulum instead of a foliot balance or balance wheel to regulate the time; these clocks are thought to be an outgrowth of the work of Christiaan Huygens the previous year. *See also* 1656 TOOL; 1670 TOOL.

1658

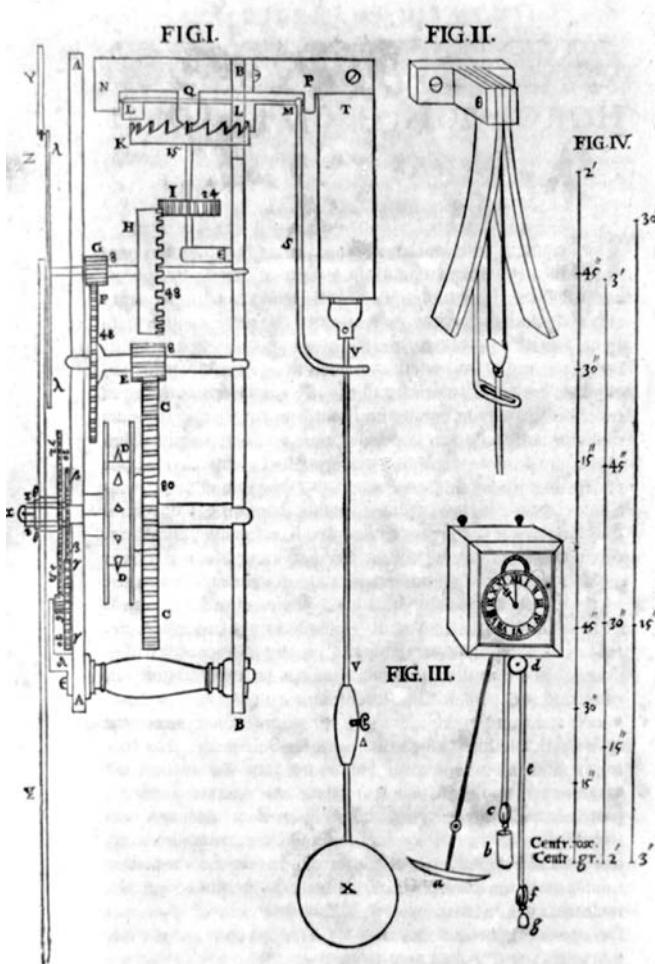
❖ Materials

The Riksbank of Sweden issues the first form of paper bank notes in Europe. *See also* 900 MATR; 1690 matr.

Σ Mathematics

Blaise Pascal, who had abandoned mathematics for religion and philosophy, has the most famous toothache in mathematics history. To relieve the pain, he returns to mathematics briefly and works out many properties of the cycloid. Also this year, while working on the sine function, he comes close to discovering the calculus.

Christopher Wren [b. East Knoyle, England, October 20, 1632, d. London, February 25, 1723] finds a formula for the length of the cycloid. *See also* 1656 MATH.



HOW HUYGENS'S CLOCK WORKED Figure I shows the gears and escapement needed to translate the beat of the pendulum into the movement of a hand on a dial. Figure II illustrates strips curved to a section of cycloid that regulated the swing of the pendulum. Figure III shows the weight whose slow fall — controlled by the escapement — powered the clock and kept the pendulum swinging.



Jan Swammerdam

[b. Amsterdam, Holland, February 12, 1637, d. Amsterdam, February 17, 1680]

One of the founders of comparative anatomy, Swammerdam made detailed microscopic studies of a wide variety of organisms. He did much to refute ancient beliefs that insects have no internal organs and that they originate by spontaneous generation. He also showed that during metamorphosis an insect changes its form and structure rather than developing suddenly from a totally different kind of organism.

♥ Medicine & health

Jan Swammerdam is the first to see and describe red blood cells.

✿ Physics

Johann Glauber's *Opera omnia chymica* ("all chemical works") is an important treatise in chemistry that is later widely reprinted. *See also* 1648 CHEM.

I Tools

Robert Hooke invents the spiral spring for watches. *See also* 1502 TOOL; 1675 TOOL.

1659

★ Astronomy

Christiaan Huygens becomes the first to observe surface features on Mars.

Robert Hooke

[b. Freshwater, Isle of Wight, England, July 18, 1635, d. London, March 3, 1703]

Hooke, like most other scientists of the 17th century, investigated what are now regarded as several different branches of science. Hooke's law is that stretching is directly proportional to force, a discovery in materials science. Hooke introduced the word *cell* to describe tiny compartments in cork. His invention of a compound microscope with a separate light source enabled him to observe not only "cells" but also the tiny parts of insects and to confirm the existence of microbes. Hooke's theory of combustion preceded the phlogiston idea by 35 years or so and was closer to what we now know to be true. Hooke's correct guess that gravity obeys an inverse square law contributed to a famous feud with Newton, who had actually proved this result. Hooke was one of the first to recognize a double star; he also proposed a wave theory of light.

☛ Energy

About this time English minister Dean John Clayton of Kildare discovers a pool of natural gas near Wigan, Lancashire. He gathers the gas with animal bladders and amuses his friends by setting it on fire. *See also* 1682 ENER.

Σ Mathematics

Elementa curvarum by Jan De Witt [b. Holland, January 1625, d. 1672] gives an algebraic treatment of conic sec-

tions using the newly developed analytic geometry. It appears as part of an edition of Schooten's *Geometria a Renato Des Cartes*. *See also* 1649 MATH.

Teutsche algebra by Johann Heinrich Rahn [b. Zurich, Switzerland, March 10, 1622, d. 1676] introduces the sign ÷ for division. *See also* 1557 MATH.

♥ Medicine & health

De febribus by Thomas Willis [b. Great Bedwyn, England, January 27, 1621, d. London, November 11, 1675] describes typhoid fever.

☛ Transportation

Christiaan Huygens constructs a chronometer for use at sea; however, it is influenced by the motion of the ship and does not keep correct time. *See also* 1533 TRAN.

JAMBE	J W HOPKINS	J H LEWIS	C A NOEL-BUXTO
R	R J HORN	M G LILLINGSTON	SIR H N S V NORM
DOWER	A R L HORNBY	H E J LISTER	BARON
	M P G HOWARD	J H LITTLE	T E S NORRIS
	A J E HOWEY	T D LITTLE	ETT NORTH
	I HOWITT	H LIVERSIDGE	REH NORTHRIDG
	T W G HULBERT	R D M C LLEWELLYN	J A NUGENT
	C S HUMPHRIES	W G LUCAS	P J R OLDFIELD
	F W JACKSON	NIXMOORE	COUNTS ORLOFF
	T R E JACKSON	LXMOORE	DAVIDO
	D H JACOBSON	McALLEN	J D H O'RORKE
	J S W JARVIE	MACCAW	A J ORR EWING
	M J EBB	McCOSH	M H OXLEY
	E G JEFFERY	EGOR	B H V PAGET
	B E JEFFREYS	BE	P W PAGET
	A A JESSUP	ON	J T M PARKER
	M A JOHNSON	IG-	R V PATTINSON
	E C KAUFFMAN	OW	W E D PAUL
	H W KEARNEY	ON	R J PEARCE
	J KEE	ND	A J PEARCE-
	D W KENT	APPEASE	SEROCO
	R G G KERRISO	H W J E PEEL	
	J F KINGSCOTE	EG PELLY	
	O C KISCH	O J PEMBERTON	
	C M KNAGGS	AL PHILLIPS	
	VISCOUNT	SIR J H PIGOTT-	
	KNEBWOLD	BROWN BARON	
	H G B KNIGHT	D J C PINCKNEY	
X	I	X	
			G M X X

NEWTON
Qui genus humam ingenio suscepit

Scientific Method: Measurement and Communication: 1660 through 1734

A convenient way to date the period of developing organization is from the founding in London of the Royal Society. The late 17th and early 18th centuries were dominated largely by the ideas of Isaac Newton and, to a lesser degree, Gottfried Wilhelm Leibniz. The second part of the 18th century, known as the Enlightenment, was a period emphasizing reasoning and order. In science, we start the Enlightenment in 1735 with the publication of the Linnaean scheme for classifying organisms.

European domination

Although this period saw both growth and consolidation in science, for most of the world it was a time of political consolidation with growth limited to a small region. Science became centered in Europe, especially England, France, and the Netherlands. By the end of this period only Antarctica and a few isolated islands had not yet been explored by Europeans, who generally took command, either directly or indirectly, of the local government and economy. In Africa, the slave trade by Arabs and Europeans completed the destruction of large states, leaving poorly organized tribes in their wake. Asia was plagued by despotic rulers who prevented change in society. The native population of the Americas was in even more disarray, largely as a result of depopulation by disease, although it was also adversely affected by slavery and war. In both the Americas and parts of Africa, the growing population of European colonists and their descendants formed new states modeled on those of western

Europe, their former home. These states were at first vassals of western Europe, contributing raw materials and buying finished goods. Meanwhile, the eastern portions of Europe and nations in Asia did not so much fall as become gradually moribund.

As a result of these trends, the people of western Europe became, by the end of this period, the richest and most technologically advanced in the world. In 700 years they had progressed from one of the least advanced societies in the world to one of the most, certainly in their own view of themselves and especially in technology — and for most of the next 300 years they would remain technologically superior. Science and technology flourished in western Europe and largely disappeared from the rest of the world.

The scientific method

The most important scientific work of the second half of the 17th century was Newton's *Principia*. Not only did it become the foundation of physics for the next 200 years, it formed the basis of the scientific method that slowly made its entry into the study of natural phenomena. Unlike Descartes, who advocated the deduction of scientific laws from metaphysical principles, Newton based his theories on the careful examination of natural phenomena. Newton called his method the "method of analysis and synthesis," a procedure that included both an inductive and a deductive stage. Theories are formulated from observations; these theories are then used to predict other phenomena. This is the essence of the classic scientif-

ic method. However, in practice, science does not operate strictly according to scientific method. Newton's most important discoveries were probably the product of intuition, which he later backed up with experiment, reasoning, and mathematics.

Every natural phenomenon, according to Newton, could ultimately be explained by mathematical law, an approach to science not necessarily antagonistic to religion. In fact, Newton and Leibniz were both deeply religious. For example, Leibniz interpreted physical laws as nature's way of achieving a maximum or minimum of certain physical quantities. The presence of a direction in nature's laws implied for him the presence of a "Perfect Being" who created the universe.

It was during this time, however, that the separation of physics and metaphysics (or philosophy) took place. For example, Newton accepted the mathematical description of gravity knowing full well that his laws of gravitation said nothing about the nature or cause of gravitation. Newton refused to frame hypotheses that were not verifiable, unlike René Descartes, who hypothesized the existence of vortices to explain gravitation.

Observation and experimentation became the pillars of scientific activity. The idea that real knowledge and wisdom could be found only in the writings of the ancients lost ground gradually. Scientists during the Scientific Revolution ceased to rely on the old masters, such as Aristotle, and started to study the results of their own observations and experiments when formulating theories. This process accelerated

Scientific Method: Measurement and Communication: 1660 through 1734

with the development of the scientific method. Scientists began recording phenomena in terms of numbers to describe such qualities as weight, volume, or temperature. Scientific instruments became widely available in every major town. The development of a working pendulum clock by Christiaan Huygens and the invention of the balance spring by Robert Hooke made the clock more of a precision instrument.

The wide experimentation of this period resulted in many observed phenomena that were not understood. Nevertheless, these experiments formed the basis for the theoretical advances in physics and chemistry at the end of the 18th and beginning of the 19th centuries. Scientists, lacking the present-day concept of energy, tried to grasp such qualities as heat, electricity, magnetism, and chemical energy by describing them in terms of material, weightless (or with negative weight) fluids capable of flowing through solids.

Newton's discovery that a single law gave an accurate description of phenomena on Earth as well as in celestial space broke down the long-held belief that the heavenly bodies were of special and divine nature. Astronomy became an extension of Newton's mechanics and the return of the great comet of 1682 in 1758 — at the time predicted by Edmond Halley — was viewed as the ultimate confirmation of the validity of Newton's theory of gravitation.

Another trend during this period was toward classification — of plants, animals, minerals, and fossils, for example, leading to the great classification schemes of Linnaeus at the beginning of the next period.

Science, still called "natural philosophy," was not yet divided into the disciplines we know today. Natural philosophy encompassed all phenomena of nature, including astronomy, optics, statics, hydraulics, and mathematics.

Chemistry was considered to be closely allied to medicine.

Science becomes a shared activity

One of the reasons for the stagnation of science during the Middle Ages was that very few could learn of new discoveries. The printing press did not exist during the Middle Ages, and there were no organizations that collected, registered, and disseminated scientific information. In the period from 1660 to 1734 science found the forms of organization it had lacked before. Today, social scientists consider the means of communication through societies and journals one of the main characteristics of science.

The first scientific societies made their appearance during the 17th century. Patterned after existing literary societies, the Accademia dei Lincei was founded early in the century in Rome and counted Galileo among its members. The society was short-lived, however (although later revived and still in existence today). It was followed in 1630 by the Accademia del Cimento ("academy of experiment") in Florence. In France the Académie des Sciences, founded in 1666, served to bring together eminent scientists from outside as well as from France. Christiaan Huygens from Holland, Ole Römer from Denmark, and Giovanni Domenico Cassini from Italy joined the Académie.

In England the Royal Society was the outgrowth of a tradition that became established at Gresham College in London. Gresham College was founded with an endowment by Sir Thomas Gresham, who was the financial adviser to Elizabeth I. Gresham College housed seven professorships: divinity, astronomy, music, geometry, law, physics, and rhetoric; the professorships of astronomy and geometry were the first in those disciplines in England.

A group of scholars started meeting informally in 1645 at the lodgings of Samuel Foster, the Gresham professor of Astronomy. Foster, who died in 1652, was succeeded by Lawrence Rooke, who continued the tradition of weekly meetings. In 1657 Rooke started teaching geometry. Christopher Wren became Gresham professor of astronomy at the age of 25. The group, which began meeting twice a week, following the lectures of Wren and of Rooke, included William Brouncker, John Wilkins, and Robert Boyle. On November 28, 1660, the group decided to organize itself as a scientific society. John Wilkins became chairman and a few days later Charles II approved the society.

The Royal Society is today the oldest scientific society in existence continuously since its founding; its journal, *Philosophical Transactions*, founded in 1664, is the oldest existing scientific journal.

Scientific societies, such as the Royal Society in England and the Académie des Sciences in France, not only stimulated scientific inquiry but also made meetings between scientists possible and increased scientific communication. The creation of scientific institutions, such as the Greenwich Observatory and the Accademia del Cimento, made scientific research a more organized undertaking. Learned journals, such as *Philosophical Transactions* and the *Journal des Savants*, provided a means of circulating ideas superior to the traditional means of correspondence between scholars. However, mathematicians did not have their scientific institutions yet and still relied on correspondence for communicating ideas, a situation which often led to disputes of priority.

Major advances

ASTRONOMY Newton's theory of gravitation provided a theoretical basis for

the Copernican system and Kepler's laws. Newton's work was also the starting point of a new field, celestial mechanics, that was to dominate astronomy for the next 200 years.

Telescopes were greatly improved as both the reflecting telescope and the achromatic lens were introduced. They pushed the limits of observational space. The idea that the Sun is but one of myriads of stars led to the view that human beings are not the center of the world, as exemplified in Bernard Fontenelle's book, *De la pluralité des mondes*.

Edmond Halley and Giovanni Domenico Cassini were the leading astronomers of the day. Halley discovered periodicity of comets and proper motion of stars; he also started to map the sky as seen from the Southern Hemisphere. Cassini explored the solar system and discovered much about its planets and moons.

BIOLOGY Anton van Leeuwenhoek, who created powerful simple microscopes (with only one lens), became the first to realize that the world is filled with creatures too small to be seen with the naked eye. His investigations of protists and sperm as well as his observations of bacteria revealed a new world. Hooke, who developed an effective form of the compound microscope, also investigated the invisible world, being the first to notice and name cells. Better microscopes changed the view held by Descartes that living animals are relatively simple machines. His mechanistic interpretation was displaced by the discovery of spermatozoa and by the discovery of the production of eggs in viviparous animals. The transmission of characteristics proper to each species formed a fundamental problem. Jan Swammerdam formulated his "preexistence theory," which assumed that the seeds of all living creatures are formed during the creation of the world, and that each generation is contained in the one before.

John Ray and other precursors to Carolus Linnaeus worked at classifying plants and animals. Physiology improved as Marcello Malpighi studied the lungs, nervous system, and physiology of invertebrates and Regnier de Graaf investigated the reproductive system.

CHEMISTRY Until this period, the study of matter relied almost completely on the traditional views of the alchemists. The alchemists had incorporated a mixture of mystical and spiritualistic notions into their body of empirical results. Jan Baptista van Helmont and Robert Boyle were among the scientists instrumental in establishing chemistry as a rational and experimental science. Boyle introduced such concepts as elements, acids, and alkalis, and developed his law of gases (although Edmé Mariotte independently discovered the same law later). While little theoretical advance was made during the period in chemistry, a number of new substances were discovered. Boyle, for example, isolated hydrogen and phosphorus (the latter independently discovered earlier by Hennig Brand). One development, however, probably held chemistry back: The phlogiston theory held that a mysterious substance with negative weight is released when something burns or rusts. The true explanation of burning, in which an ordinary gas with positive weight combines with material being burned, had to await the work of Lavoisier near the end of the 18th century.

ENERGY From the beginning of this period, scientists were experimenting with static electricity and by the end of the period they were beginning to understand it. Current electricity, however, was still nearly a century away. The first steam engines, pumping water out of coal mines, appeared in England. More coal could be mined from deeper levels, clearing the way for Britain's Industrial Revolution.

MATERIALS The main source of energy after water became coal in western

Europe as forests were mostly exhausted. Abraham Darby's discovery of how to make iron with coal made coal even more important to the new technology. Toward the end of the period, the role of carbon in the various alloys of iron began to be understood, leading to better production of steel.

This period was one of considerable growth in ceramics in the Western world as potters in Germany, the Netherlands, France, and England learned to imitate developments that had long been in place in eastern Asia.

MATHEMATICS In mathematics, everything led toward the development near the end of the 17th century of the differential and integral calculus by both Newton and Leibniz; however, there were many strides forward in side branches. The role of mathematics in the natural sciences also changed drastically. Mathematics became fully the language of science. Leibniz promoted mathematics to the level of a universal language, hoping it could be applied in domains other than scientific ones that require logical reasoning.

Statistics got started with the work of John Graunt, Jan de Witt, John Arbuthnot, and Abraham De Moivre. At the same time, the Bernoulli family continued to develop probability theory.

New tools were developed that are still useful today. Mathematical induction, known earlier but popularized by the posthumous publication of a book by Blaise Pascal, is a method for proving the truth of a statement about integers. The calculus of variations, developed initially by Jacques Bernoulli, is a method for finding the maximum or minimum of a function.

MEDICINE & HEALTH Progress in biology, such as fundamental observations with microscopes, had an impact on medicine that would be felt when people started to apply their learning. Anatomists continued their description of the

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parts of the human body, such as the brain and the ear. Bernardino Ramazzini became the first doctor to note that certain kinds of cancer can be associated with environmental effects. Basic physiological measurements became easier with the availability of better thermometers and the first experiments in finding blood pressure.

Toward the end of the period people began using inoculation, although not yet vaccination, to protect against smallpox — that is, they would deliberately expose themselves to smallpox so that later they would not catch it. (Vaccination involves exposure to a different, related virus, one that does not itself cause smallpox.) Smallpox was having one of those virulent pandemics that viruses seem to have from time to time, so inoculation quickly spread from Turkey to England to the American colonies. This was the first step toward one of the most amazing technical achievements in medicine, the complete elimination of smallpox as a disease.

PHYSICS The major development in physics was Newton's formulation of

his laws of motion, foreshadowed by Galileo in the 17th century. Galileo's work had shown the need for a force to keep planets in their orbits, since otherwise inertia would cause the planets to travel in straight lines. Newton's law of universal gravitation provided the theoretical foundation for Johann Kepler's laws and Galileo's observations. Descartes' theory of vortices remained the only one accepted in France for a while, but it was discarded when sufficient proof for the validity of Newton's theory became available.

There were also many advances in the theoretical understanding of light, ranging from the first mathematical treatment of refraction to the discovery of the speed of light. Both the wave and particle theories of light were advanced during this time, ultimately to be superseded in the 20th century by the quantum theory, which combines wave and particle aspects.

After Otto von Guericke discovered how to create large amounts of static electricity, the move to investigate electric phenomena gained momentum,

although it was to reach greater heights in the 18th and early 19th centuries.

TOOLS Great advances in the art of clock making and pumps occurred throughout this period. Lathes were adapted to turn iron. Not all new inventions during this period, such as improvements in weaving, including the flying shuttle, were appreciated by workers, many of whose jobs were displaced. These inventions, however, were fore-runners of the Industrial Revolution.

TRANSPORTATION The main accomplishment during this period was the construction of important canals in France — a harbinger of even greater dependence on canals throughout Europe at the dawn of the Industrial Revolution. Many innovative ideas were proposed that did not reach fruition until years or even centuries later. Newton proposed both a form of rocket propulsion and the artificial satellite, for example. Understanding more about air pressure and the vacuum led to both the impractical notion of an airship using a vacuum as a balloon and Halley's practical invention of the diving bell.

CHRONICLE

1660

Biology

Marcello Malpighi discovers that the lungs consist of many small air pockets and a complex system of blood vessels. By observing capillaries through a microscope he completes the work of Harvey in describing the circulation of the blood. *See also* 1616 MED; 1665 BIO.

Chemistry

Robert Boyle announces in *New Experiments Physico-*



Marcello Malpighi

[b. Crevalcore (Italy), March 10, 1628, d. Rome, November 30, 1694]

A pioneer in the use of the recently invented microscope, Malpighi located the capillaries that carry blood from the arteries to the veins. He also identified sensory receptors (papillae) of the tongue and skin and capsules of the kidney and spleen. He showed that there is no such thing as black bile, which since ancient times had been believed to be one of the four humors (fluids) of the human body, together with yellow bile, blood, and phlegm.

Mechanical Touching the Spring of Air that removing the air in a vacuum chamber extinguishes a flame and kills small animals, indicating that combustion and respiration are similar processes. *See also* 1667 MED.

Communication

The Royal Society is founded in England, first as the "Invisible College for the promoting of Physico-Mathematical Experimental Learning." It becomes the Royal Society for the Improvement of Natural

Knowledge when Charles II seals its charter in 1663. *See also* 1645 COMM; 1666 COMM.

Earth science

Otto von Guericke observes that air pressure drops before a storm. He becomes the first



Robert Boyle

[b. Lismore Castle, Ireland, January 25, 1627, d. London, December 30, 1691]

Boyle's name is most closely associated with his contribution to the gas laws, but his greatest influence was on chemistry. He was the first to develop modern concepts of element and compound; to distinguish between acids, bases, and neutral substances; and to conduct and publish experiments along the lines now called the scientific method. In his work with a vacuum he demonstrated that all masses fall toward Earth with the same acceleration and that the vacuum does not conduct sound but does conduct the electric force.

to use a barometer to forecast weather. *See also* 1643 TOOL.

Energy

Otto von Guericke develops a way to charge a ball of sulfur with static electricity, producing the greatest amount of electricity, other than lightning, gathered in one place to this time. *See also* 1650 ENER; 1709 ENER.

Materials

By this date England is producing 2,000,000 tons of coal a year, more than 80 percent

of all the coal produced in the world.

Medicine & health

Edmé Mariotte [b. Dijon, France, 1620, d. Paris, May 12, 1684] discovers the blind spot in the eye.

1661

Chemistry

Robert Boyle's *The Sceptical Chymist* introduces the modern concepts of element, alkali, and acid and refutes many of the ideas of Aristotle and

Paracelsus on the chemical composition of matter. He differentiates compounds from mixtures.

Tools

Christiaan Huygens invents a manometer for measuring the elasticity of gases.

1662

Astronomy

Marquis Cornelio Malvasia [b. (Italy), 1603, d. 1664] invents a form of the micrometer for use with telescopes. It consists

of a grid of fine silver wires. Distance is measured by counting the cells between two positions of a star. *See also* 1639 TOOL; 1667 AST.

Chemistry

Robert Boyle asserts that in an ideal gas under constant temperature, volume and pressure vary inversely (Boyle's law). *See also* 1676 PHY.

Communication

Mathematician William Brouncker becomes the first president of the Royal Society. *See also* 1660 COMM; 1703 COMM.

Construction

The Sheldonian Theatre in Oxford, England, designed by Christopher Wren, is completed. Although superficially different from the Gothic style used for Oxford University, the techniques used for construction of the roof are still based on Gothic methods.

The first statistician

When the Royal Society was founded in 1660, the founding members were scientists, doctors, noblemen, lawyers, civil servants, and literary men. Two years later, the question arose as whether to admit a tradesman, a draper in fact. The members asked their patron, Charles II, what to do. Not only did he recommend admitting him, but added that if they could find any other tradesmen like him, the others should be admitted as well.

The draper in question was John Graunt, who wrote a remarkable book, published in 1662. Ever since 1563, the parish clerks of London had compiled records of the number of people buried. Starting with the barest information possible, these bills of mortality gradually began to include details about the causes of death. Beginning in 1625, the bills of mortality for each year were published. People who bought the published versions were mainly looking for unusual occurrences that would provide

interesting gossip. John Graunt had the idea that there might be more to the bills than that. He obtained all of them from 1604 through 1661 and compiled the information. The compilation, with his analysis, was published as *Natural and Political Observations Made upon the Bills of Mortality*.

Using his records, Graunt became the first to note such now familiar statistics as the following: More boys are born than girls; women live longer than men; and, except in epidemics, the number of people dying each year is relatively constant. Graunt also noted that male mortality was such that, by a suitable age for matrimony, the excess of boys over girls had vanished, so "every woman may have a husband, without the allowance of polygamy."

Graunt's most important innovation was the first mortality table, a table that could be interpreted to show how long a life might be expected after a given age. With this kind of information in hand, it was not long (37 years) before the first life insurance company was founded.

🍴 Food & agriculture

Georg Andreas Bockler changes Agostino Ramelli's design for a roller mill by adding a second corrugated, grooved roller. *See also* 1588 FOOD; 1834 FOOD.

Σ Mathematics

Natural and Political Observations Made upon the Bills of Mortality by John Graunt [b. London, April 24, 1620, d. London, April 18, 1674] is the first book of statistics. It contains the London Life Table, the first table showing the ages at which people (in London) are likely to die. *See also* 1761 MATH.

✈ Transportation

Blaise Pascal proposes the introduction of a public transport system in Paris. Coaches would travel along predetermined routes and take passengers for a small fee. The first coach goes into service during the following year. *See also* 1564 TRAN.

1663

★ Astronomy

Optica promota by James Gregory [b. Drumoak, Scotland, October 1638, d. Edinburgh, Scotland, October 1675] gives the first description of a reflecting telescope; that is, a telescope that focuses light with a mirror rather than a lens. *See also* 1611 TOOL; 1668 AST.

⌚ Communication

Descartes' works are placed on the Roman Catholic Church's Index of Prohibited Books, despite his obvious efforts to avoid this fate. *See also* 1664 AST.

⚡ Energy

The Marquis of Worcester claims to have discovered the power of steam to raise water from wells and to burst cannons. *See also* 1629 ENER; 1690 ENER.

Σ Mathematics

Isaac Barrow [b. London, October 1630, d. London, May 4, 1677] becomes the first Lucasian Professor of mathematics at Cambridge and inspires Newton to adopt an academic career. *See also* 1669 MATH.

Girolamo Cardano's hundred-year-old *Liber de ludo aleae* ("book on games of chance") is published posthumously. It is the first known work on the theory of probability, although not the first to be published. It includes advice on how to cheat to increase the probability of winning. *See also* 1657 MATH; 1686 MATH.

John Wallis shows that the assumption that for every triangle there is a similar triangle of arbitrary size is equivalent to Euclid's Fifth, or Parallel, Postulate. *See also* 1733 MATH.

⌘ Physics

Blaise Pascal's *Traité des l'équilibre des liqueurs* ("on the equilibrium of liquids"), published posthumously, suggests that in a fluid, pressure is transmitted equally in all directions (Pascal's law). Pascal probably discovered this around 1648. *See also* 1662 CHEM; 1795 TOOL.

1664

★ Astronomy

Descartes' *Le monde* ("the world"), published posthumously, affirms the Copernican theory. Descartes had



GREAT RED SPOT ON JUPITER Hooke was the first to spot this giant storm in 1664, now at least 340 years old and still present.

abandoned this project after learning of Galileo's problems with the Roman Catholic Church. *See also* 1663 COMM; 1686 COMM.

Robert Hooke discovers the Great Red Spot (an extremely persistent storm) on Jupiter and uses it to determine the period of Jupiter's rotation, which is astonishingly less than ten hours despite Jupiter's great size. *See also* 1666 AST.

Giovanni Alfonso Borelli [b. Naples (Italy), January 28, 1608, d. Rome, December 31, 1679] calculates the orbit of a comet and finds that it is a parabola (not a circle, ellipse, or line as expected in various earlier theories). *See also* 1609 AST.

🔬 Biology

Descartes' *Traité de l'homme et de la formation de foetus* ("treatise on man and the formation of the fetus"), printed posthumously, describes animals as purely mechanical beings; that is, there is no "vital force" that makes animals different from other material objects. *See also* 1686 COMM.

⌚ Communication

Voltaire (François-Marie Arouet) [b. Paris, November 21, 1694, d. Paris, May 30, 1778] publishes *Dictionnaire philosophique* ("philosophical dictionary"), which gives his candid opinions from A to Z on such topics as adultery, animals, climate, common sense, limits of the human mind, natural law, and truth. *See also* 1765 COMM.

❖ Materials

Cast iron is used for the pipes supplying water to the gardens at Versailles.

♥ Medicine & health

Thomas Willis's *Cerebri anatome* ("anatomy of the brain") is the most complete and accurate account of the brain and nervous system put forward so far. *See also* 1665 BIO.

⌘ Physics

Christiaan Huygens proposes that the length of a pendulum with a period of one second should be the standard unit for length. *See also* 1670 EAR.

I Tools

Gaspar Schott [b. Königshofen (Germany), February 5, 1608, d. Augsburg (Germany), May 22, 1666] gives a description of a universal coupling (Cardan joint). *See also* 1676 TOOL.

1665

★ Astronomy

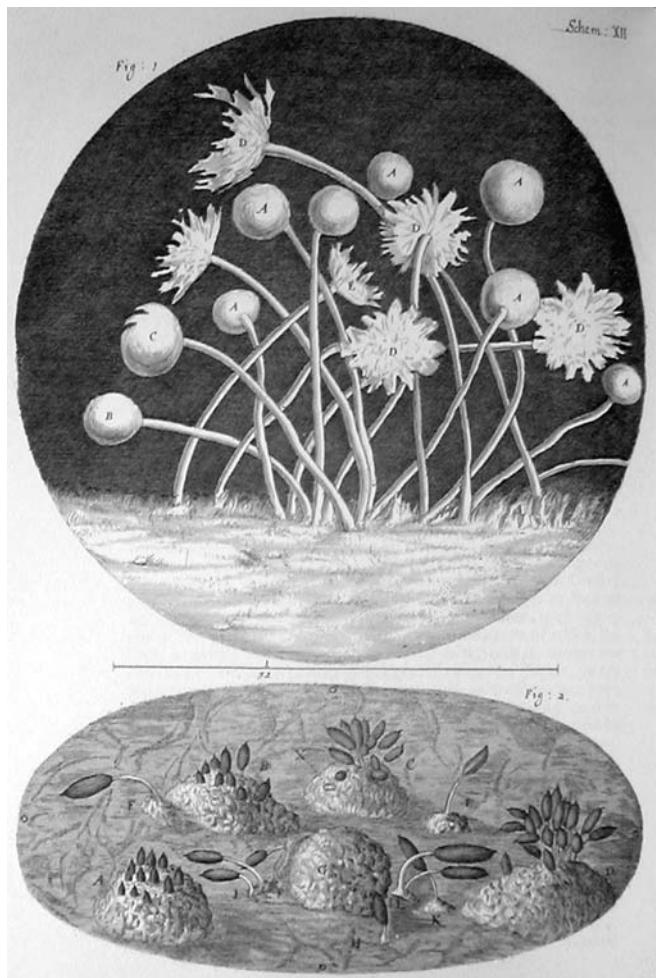
Giovanni Cassini measures the rotational speed of Jupiter, previously measured by Robert Hooke. *See also* 1664 AST.



Giovanni Domenico (Jean-Dominique) Cassini

[b. Perinaldo (Italy), June 8, 1625, d. Paris, September 14, 1712]

Cassini's work established much of what we know of the solar system, including size, rotational periods of nearby planets, exact orbits of the moons of Jupiter, satellites of Saturn, and the gap in Saturn's rings named after him. He used parallax with a second observer on the other side of Earth to find the distance to Mars, from which other solar system distances can be computed.



EXAMPLE FROM HOOKE'S MICROGRAPHIA Two drawings from *Micrographia* show blue mold growing on a sheepskin book cover, which Hooke likened to tiny mushrooms, and a yellow spot on the leaf of a damask rose, which reminded Hooke of the spore capsules of the much larger moss that grows on soil. In fact, both mold and mildew are fungi, related to mushrooms.

■ Construction

Physician and architect Claude Perrault [b. Paris, September 25, 1613, d. Paris, October 11, 1688] begins work on the facade for the Louvre known as the *Colonnade*, a project that will not be completed until 1680. See also 1673 CONS.

■ Earth science

Robert Hooke uses the microscope to study fossils, describing fossil mollusk shells and comparing them to shells of living mollusks. He believes the fossils are remains of once-living animals. See also 1500 EAR; 1667 EAR.

■ Biology

Marcello Malpighi describes in *De cerebro* how the nervous system consists of bundles of fibers connected to the brain by the spinal cord. See also 1660 BIO; 1666 MED.

Robert Hooke's *Micrographia*, with illustrations of objects viewed through a microscope, appears. The book greatly influences both scientists and educated laypeople. In it, Hooke describes cells (viewed in sections of cork) for the first time. See also 1838 BIO.

■ Communication

Science administrator Henry Oldenburg [b. Bremen (Germany) c. 1618, d. London, September 5, 1677] founds *Philosophical Transactions*, the first scientific journal and the main publication of the Royal Society. As secretary of the Royal Society from 1663 through 1677, the time of Newton and Leibniz, he becomes the recipient of many formal letters announcing developments in the calculus, often serving as a link between the two mathematicians. See also 1660 COMM; 1682 COMM.

Publication of *Journal des savants* ("journal of wise men") begins in France. See also 1666 COMM.

■ Materials

Hooke proposes that artificial silk might be manufactured by extruding a solution of a gum. See also 1892 MATR.

In his *Metalum martis* Dud Dudley claims to have learned the secret of making iron with coal instead of charcoal. Previously, his father, Lord Dudley, had been granted a patent for this process. Despite the patent and the claim, modern writers have generally assumed that the process would not have worked for iron of any usable quality since it called for coal instead of coke. See also 1621 MATR; 1709 MATR.

■ Mathematics

Blaise Pascal's 1654 work *Traité du triangle arithmétique* ("treatise on figurative numbers"), published posthumously, introduces mathematical induction to most mathematicians. Although the first use of mathematical induction was in 1575, the method had failed to have any impact until Pascal's use. See also 1575 MATH; 1666 MATH.



Isaac Newton

[b. Woolsthorpe, England, December 25, 1642 (January 4, 1643, by Gregorian calendar), d. London, March 20, 1727]

Newton entered Cambridge University in 1661, but in 1665, Cambridge closed because of plague and Newton returned to the family farm for a year and a half. During this period in the country Newton first developed new methods in mathematics, starting with the binomial theorem, which deals with fractional powers of an algebraic expression, and continuing with a useful method for approximating solutions. By the end of 1665, he had developed the methods for finding slopes of curves that we call differential calculus. In the following year, he completed his invention of calculus with the method of finding areas of curved regions (the integral calculus). During the same period, Newton experimented with light and found that white light is a mixture of colors. He also began to think about gravity — whether the same force that causes an apple to fall to Earth also affects the Moon.

Newton completed his studies at Cambridge and stayed as a professor of mathematics. Instead of publishing his work he circulated manuscripts to friends. He built the first reflecting telescope and in 1672 presented one to the Royal Society. The Royal Society elected him a fellow and he began to communicate some of his discoveries about optics to them. He was urged to publish his ideas on the motion of planets, and Newton's *Principia* of 1687 contained his laws of motion and gravity as well as such topics as artificial satellites.

In 1696 Newton left Cambridge and took charge of the British Mint in London. In 1703 he became president of the Royal Society, keeping that post for the rest of his life. The following year he wrote a full account of his study of light, called *Opticks*. Although Newton devoted a major portion of his time to alchemy, the predecessor of chemistry, he did not publish any results.

Isaac Newton discovers the general binomial theorem in either this year or in 1664. *See also* 1669 MATH.

❖ Physics

The Great Plague in London kills 75,000 and closes Cambridge for two years. Newton retires to the country, where he begins to develop the first version of his law of universal gravitation. According to Newton's later reconstruction, he observes an apple fall and realizes that the Moon must also be attracted toward Earth (modern scholars, however, think Newton invented this story in his old age). *See also* 1687 PHY.

Robert Hooke's *Micrographia*, fundamentally the first book dealing with observations through a microscope, compares light to waves in water. *See also* 1678 PHY.

Physico-mathesis de lumine coloribus et iride ("physics of light, colors, and the rainbow") by Francesco Maria Grimaldi [b. Bologna (Italy), April 2, 1618, d. Bologna, December 28, 1663], pub-

lished posthumously, describes Grimaldi's experiments with diffraction of light and his theory that light is a wave phenomenon. It also notes his observation that muscles make sound as they expand and contract. *See also* 1678 PHY.

1666

★ Astronomy

Giovanni Cassini observes the polar ice caps of Mars. *See also* 1664 AST.

❖ Communication

The Académie Royale des Sciences is founded in Paris. Christiaan Huygens, along

with 19 other scientists, is elected as a founding member. After the French Revolution, the *Royale* is dropped and the character of the academy changes. It later becomes the Institut de France. *See also* 1660 COMM; 1697 COMM.

□ Computers

Disserto de arte combinatoria ("discussion of the combinatorial art") by Gottfried Wilhelm Leibniz contains his suggestion, based on the work of Raymond Lully, that a mathematical language of reasoning be developed. It will not be until the 19th century that George Boole and others develop this idea further. Some of the outgrowths of

this idea find application in computer science and artificial intelligence research. *See also* 1854 COMP.

■ Food & agriculture

Cheddar cheese is invented in the English village of Cheddar.

❖ Materials

Because almost all European paper is made from recycled cloth rags, which are becoming increasingly scarce as more and more books and other materials are printed, the English Parliament bans burial in cotton or linen cloth so as to preserve the cloth for paper manufacture. *See also* 1391 MATR; 1798 MATR.

Gottfried Wilhelm Leibniz

[b. Leipzig (Germany), July 1, 1646, d. Hanover (Germany), November 14, 1716]

Leibniz is best known for having invented the calculus independently from Newton; much of the notation and vocabulary used today comes from Leibniz, who had a flair for both symbolism and language. He also took the first steps in symbolic logic. The calculating machine Leibniz invented was the first to multiply as well as add and subtract. In physics he contributed to developing the idea of kinetic energy.



Mad Madge, the scientist

Throughout history men have erected barriers between women and scientific knowledge. Seventeenth-century England was no exception. Henry Oldenburg, the first secretary of the Royal Society, called science "masculine philosophy" in 1664. Thomas Spratt, the contemporary bishop of Rochester, also termed this new form of knowledge "masculine and durable."

In the beginning of modern science, Margaret (Lucas) Cavendish, duchess of Newcastle, fought against these prejudices. As a result of her interest in science, she came to be known as "Mad Madge." Despite this, she wrote prolifically about the nature of the new science. She also was among the earliest science-fiction novelists and wrote plays and poems celebrating what today would be called feminist ideals.

Since the Royal Society was at the core of British science at the time, the duchess was determined to become a member. This campaign of hers was the talk of London, and Samuel Pepys recorded in his diary that "the town will be full of balades of it." In the face of opposition from Pepys and others, however, the duchess succeeded in becoming a member on May 30, 1667.

Contemporary descriptions of Duchess Margaret present a mixed picture. John Evelyn said he was "much pleased with the extraordinary fancifull habit, garb and discourse of the Duchess." His wife, on the other hand, found the duchess's conversation as "airy, empty, whimsical, and rambling as her books, aiming at science, difficulties, high notions, terminating commonly in nonsense, oaths, and obscenity."

No other woman was admitted to the Royal Society until 1945.

Σ Mathematics

Newton describes his early work on the calculus in an untitled manuscript known to historians as the October 1666 Tract. It includes the method for finding the area between a curve that is the graph of an equation and the horizontal axis. This method is now known as the integral calculus. *See also* 1655 MATH; 1669 MATH.

Michelangelo Ricci [b. Rome, January 30, 1619, d. Rome, May 12, 1682] writes *Exercitatio geometrica, de maximis et minimis* ("geometrical exercises concerning maximums and minimums"), later reprinted as an appendix to Nicolaus Mercator's *Logarithmo-technia* (1668). Ricci finds the maximum of $x^m(a-x)^n$ and the tangents to $y^m = kx^n$ using a version of mathematical induction. As a cardinal, Ricci supports the work of such mathematicians as Stefano degli Angeli and is a close friend of Torricelli. *See also* 1665 MATH.

♥ Medicine & health

Physician Thomas Sydenham [b. Wynford Eagle, England, September 10, 1624, d. London, December 29, 1689] publishes *Methodus curandi febres* ("ways to cure fevers"). In this and other books, he advocates the use of opium to relieve pain, cinchona bark (quinine) to relieve malaria, and iron to relieve anemia. *See also* 1520 MED.

Richard Lower [b. Cornwall, England, c. 1631, d. London, January 17, 1691] demonstrates the direct transfusion of blood between two dogs. *See also* 1660 BIO; 1667 MED.

Marcello Malpighi explains that bile is secreted by the liver. *See also* 1665 BIO; 1669 BIO.

❀ Physics

Robert Boyle's *Hydrostatical Paradoxes* reports his experiments with fluids. *See also* 1640 PHY.

Boyle's *The Origine of Formes and Qualities* contains his view that everything is built of

atoms and reflects his mechanical view of nature. *See also* 50 BCE PHY; 1803 CHEM.

While still in the country to avoid the plague, Newton discovers that the spectrum of light is made from white light. *See also* 1704 PHY.

Midi (also known as the Languedoc Canal and the Canal of the Two Seas], connecting the Mediterranean Sea and the Bay of Biscay in the Atlantic Ocean, using the River Garonne. *See also* 1642 TRAN; 1681 TRAN.

1667

★ Astronomy

The observatory of the French Academy is founded in Paris. *See also* 1666 COMM; 1669 AST.

Traité du micromètre ou manière exacte pour prendre le diamètre des planètes et la distance entre les petites étoiles ("treatise on the micrometer or the exact method for measuring the diameter of the planets and the distance between the little stars") by Adrien Auzout [b. Rouen, France, January 28, 1622, d. Rome, May 23, 1691] discusses Auzout's improvements of the telescope, including his independent invention of the micrometer. *See also* 1662 AST; 1754 AST.

→ Transportation

Pierre-Paul Riquet [b. Béziers, France, June 29, 1609, d. 1680] starts construction on the 290-km (180-mi) Canal du

Abbé Jean Picard [b. La Flèche, France, July 21, 1620, d. Paris, July 12, 1682] develops his own version of the micrometer for use with a telescope and with it discovers anomalies in the positions of stars. These changes in position will be explained by James Bradley in 1728 as due to the aberration of light. *See also* 1684 AST.

Earth science

Nicolaus Steno [b. Niels Stenson, Copenhagen, Denmark, January 11, 1638, d. Schwerin (Germany), November 25 or December 5, 1686], after dissecting the head of a large shark, proposes that fossils known as tongue stones, previously thought to be stones that fell from the sky or that grew in rocks, are actually sharks' teeth, arguing for the organic origin of fossils. *See also* 1665 EAR; 1669 EAR.

Medicine & health

Jean-Baptiste Denis [b. Paris, 1640, d. Paris, October 3, 1704] transfers about 350 ml (12 oz) of lamb's blood into a sick boy, who recovers. Later experiments are not so successful. When two of his patients die after receiving blood from sheep, Denis is tried for murder. He is acquitted, but such transfusions are banned in France. *See also* 1666 MED; 1669 MED.

Thomas Willis's *Pathologiae cerebri* ("pathology of the brain") contains the first account of effects of the late stage of syphilis on the brain (although Willis did not recognize the cause of these symptoms). *See also* 1530 MED.

In an experiment demonstrated before the Royal Society,

Robert Boyle shows that an animal can be kept alive by artificial respiration. *See also* 1660 CHEM.

Tools

Robert Hooke invents the anemometer for measuring wind speed. Hooke introduces adding red dye to alcohol in his version of the thermometer and uses the freezing point of water as zero. *See also* 1654 TOOL; 1702 TOOL.

1668

Astronomy

Giovanni Cassini's *Ephemerides bononienses Mediceorum siderum* ("timetable of the Medicean stars") contains his computation of the movements and eclipses of the four satellites of Jupiter. *See also* 1664 AST; 1677 AST.

Newton invents the reflecting telescope, building the first telescope based on a mirror (reflector) instead of a lens (refractor). *See also* 1663 AST.

Biology

Francesco Redi [b. Arezzo (Italy), February 18, 1626, d. Pisa (Italy), March 1, 1697] disproves the idea that maggots arise spontaneously in rotten meat in one of the first controlled experiments in science. By showing that flies are not produced spontaneously from rotting meat, he partially disproves the theory of spontaneous generation. The theory will be definitively shown to be false by Louis Pasteur in 1859.

John Mayow [b. Bray, England, December 1641, d. London, September 1679] recognizes the similarities between

respiration and combustion. *See also* 1660 CHEM; 1674 CHEM.

Mathematics

James Gregory's *Geometriae pars universalis* ("the universal part of geometry") and *Exercitationes geometricae* ("geometrical exercises") include a geometrical version of the fundamental theorem of the calculus (that differentiation and integration are inverse operations) as well as the series named after him. In a different publication this year, Michelangelo Ricci states explicitly that finding tangents and finding areas are inverse operations, essentially the same idea. *See also* 1666 MATH; 1669 MATH.

Logarithmotechnia by Nicolaus Mercator [b. Niklaus Kaufmann, Holstein, Denmark, c. 1619, d. Paris, January 14, 1687] includes various calculations of natural logarithms and methods of approximating them by series.

Medicine & health

Regnier de Graaf [b. Schoonhoven (Netherlands), July 30, 1641, d. Delft (Netherlands), August 21, 1673] studies the testicles. *See also* 1672 BIO.

Physics

John Wallis is the first to suggest the law of conservation of momentum (the product of the mass and velocity of interacting objects is the same after the interaction as before).

1669

Astronomy

Giovanni Cassini arrives in Paris to consider taking an

appointment as the director of the Paris Observatory of the French Academy, a position he formally assumes in 1671. Because he will remain in France and become a French citizen, he is frequently cited in reference works as Jean-Dominique. *See also* 1667 AST; 1675 AST.

Geminiano Montanari [b. Modena (Italy), June 1, 1633, d. Padua (Italy), October 13, 1687] discovers the variability of the star Algol (Beta Persei). He publishes his report on this in 1672. *See also* 1638 AST; 1687 AST.

Biology

Marcello Malpighi's *De bombyce* ("silkworms"), a work on the silkworm moth, contains the first detailed description of the anatomy of an invertebrate. *See also* 1666 MED; 1673 BIO.

Jan Swammerdam writes a general treatise on insects, *Historia insectorum generalis*. He overthrows the idea of instant metamorphosis, describing the stages in metamorphosis of insects. He also describes the reproductive parts of insects in detail. *See also* 1734 BIO.

Chemistry

Physica subterranea ("subterranean physics") by Johann Joachim Becher [b. Speyer (Germany), May 6, 1635, d. London, October 1682] contains alchemical ideas and experiments on the nature of minerals and other substances. Becher's concept that *a terra pinguis* ("oily earth") causes fire later becomes the basis of the phlogiston theory. *See also* 1697 CHEM.

Hennig Brand [b. Hamburg (Germany), 1630, d. (unknown)] discovers phosphorus accidentally in an experiment with urine, but keeps the discovery secret. This is the first discovery of an element unknown in antiquity. *See also* 1680 CHEM.

Earth science

De solido intra solidum naturaliter contento dissertationis prodromus ("forerunner of a dissertation about a solid body enclosed by a process of nature within a solid") by Nicolaus Steno gives a correct explanation of fossils and rock strata. Steno recognizes that different rock strata were deposited at different times and that in undisturbed situations lower layers are older than those above them. *See also* 1667 EAR; 1673 EAR.

Mathematics

Newton's *De analysi per aequationes numero terminorum infinitas* ("on the analysis by equations unlimited in the number of their terms"), circulated privately, contains his binomial theorem and methods for finding the areas under curves. John Collins [b. Wood Eaton, England, March 5, d. London, November 10, 1683] is known to have made a copy of Newton's *De analysi* and circulated it to several other mathematicians. This is the principal evidence that Newton has priority in the development of the integral calculus. *See also* 1665 MATH; 1685 MATH.

Medicine & health

Richard Lower's *Tractatus de corde* ("a treatment of the heart") describes the structure of the heart and its properties

as a muscle. It notes that blood changes color in the lungs. Lower observes that contact with air turns dark blood from the veins bright and establishes that phlegm does not, as Galen claimed, originate in the brain. *See also* 1666 MED.

Physics

Isaac Barrow's *Lectiones opticae* ("optical lectures") are published with the assistance of Newton. *See also* 1704 PHY.

Experimentia crystalli Islandici disdiastatici ("a study of Iceland spar") by Erasmus Bartholin [b. Roskilde, Denmark, August 13, 1625, d. Copenhagen, November 4, 1698] describes Bartholin's discovery of double refraction. Iceland spar, a crystalline form of calcite, refracts an image at two different angles. *See also* 1808 PHY.

1670

Chemistry

Robert Boyle discovers a flammable gas produced when certain metals are treated with acids. This gas is rediscovered in 1766 by Cavendish, who is generally given credit for its discovery. The gas is now known as *hydrogen*. *See also* 1766 CHEM.

Earth science

Gabriel Mouton [b. Lyons, France, 1618, d. Lyons, September 28, 1694] proposes the 1/60 part of a degree of the meridian of Earth as a unit for a decimal system of measure. *See also* 1664 phy; 1671 EAR.

Mathematics

Isaac Barrow's *Lectiones geometricae* ("geometry lectures") presents his theorems con-

cerning drawing tangents to curves, finding lengths of curves, and the areas bounded by curves using methods similar to those of the calculus. *See also* 1666 MATH.

Medicine & health

Thomas Willis announces his rediscovery of the connection between sugar in the urine and diabetes mellitus (a connection also known to the Greeks, Chinese, and Indians). *See also* 643 MED; 1889 MED.

Tools

William Clement of England invents the recoil, or anchor, escapement, which controls the amplitude of the pendulum (a smaller arc makes for a more accurate clock). Clement's escapement becomes the standard used in household clocks, such as the "grandfather" clocks of the English and Americans or the mantel clocks of the French. He also invents the minute hand. *See also* 1657 TOOL; 1715 TOOL.

Transportation

Francesco de Lana [b. Brescia (Italy), December 10, 1631, d. Brescia, February 22, 1687] designs an airship — never built — that would be lifted by four copper spheres containing a near vacuum. *See also* 1783 TRAN.

Naval shipwright Anthony Deane [b. 1638, d. 1721] publishes his *Doctrine of Naval Architecture*, an influential technical work on the design of warships.

A Jesuit priest living in China supposedly develops a vehicle that is propelled by a form of steam turbine. *See also* 1789 TRAN.

1671

Astronomy

Giovanni Cassini calculates the distance from Earth to Mars, which enables him to determine the distance of all the planets from the Sun. His calculation is in near agreement with modern measurements. *See also* 1676 AST.

Cassini discovers Iapetus, a satellite of Jupiter. *See also* 1668 AST; 1672 AST.

Biology

Francesco Redi dissects the torpedo fish and studies its electric organ. He fails to recognize, however, that the shocking sensation produced by touching the torpedo is caused by electricity. *See also* 1680 BIO.

Earth science

Measure de la terre ("measure of the Earth") by Jean Picard includes his determination of the length of a meridian of latitude, the most accurate figure since the ancient Greeks and very close to today's accepted values. *See also* 1670 EAR; 1792 EAR.

Food & agriculture

A fire destroys a large part of the library at the Spanish palace and monastery El Escorial, taking with it the original drawings of native American plants compiled in the 1570s by Francisco Hernández [b. near Toledo, Spain, c. 1517, d. Madrid, 1587] and Aztec artists and draftsmen. Copies of the drawings, but not of the notes in the Aztec language, were first published in 1635. *See also* 1552 FOOD.

Σ Mathematics

Newton writes *De methodis serierum et fluxionum* (“on the method of infinite series and fluxions”), a description of his version of the calculus, but does not publish it. *See also* 1736 MATH.

Jan De Witt’s *Waerdye van lyfrenten naer proportie van losrenten* (“a treatise on life annuities”) introduces the concept of mathematical expectation. *See also* 1662 MATH.

James Gregory discovers the series expansion for $\pi/4$ that is later rediscovered by Leibniz and is known as the Leibniz series. *See also* 1673 MATH; 1717 MATH.

1672

★ Astronomy

A Frenchman named either Guillaume or N. Cassegrain invents the type of reflecting telescope that is named after him, the Cassegrain. It uses a hyperboloid mirror to reflect the image collected by a parabolic mirror through a hole in the parabolic mirror. *See also* 1668 AST.

Ⓑ Biology

Regnier de Graaf discovers and describes the ovarian follicle that is named after him, the Graafian follicle.

Ⓔ Earth science

Jean Richer [b. France, 1630, d. Paris, 1696] finds on an expedition to Cayenne that a pendulum of the same length has a longer period on the equator than in France. In 1687 Newton shows that this is because of a bulge at the equator and a flattening at the

poles that is predicted by his theory of gravity. *See also* 1664 PHY; 1679 EAR.

Σ Mathematics

Euclides danicus (“the Danish Euclid”) by Georg Mohr [b. Copenhagen, Denmark, April 1, 1640, d. Kieslingswalde (Germany), January 26, 1697] contains Mohr’s proof that all geometric figures constructible by straightedge and compass are also constructible with compass alone. This is known as Mascheroni’s theorem, although Mascheroni was not to publish it until 1797. *See also* 1797 MATH.

Il problema della quadratura del circolo (“the problem of squaring the circle”) by Pietro Mengoli [b. Bologna (Italy), 1625, d. Bologna, 1686] introduces many infinite series and products, containing many results, such as the divergence of the harmonic series and the sum of the reciprocals of the triangular numbers, often attributed to others. *See also* 1671 MATH; 1676 MATH.

♥ Medicine & health

Francis Glisson [b. Rappisham, England, 1597, d. London, October 16, 1677] gives a description of the “irritability” of living tissues, or the tendency of tissues to react to their environment, in *Tractatus de natura substantiae energetica*.

Thomas Willis’s *De anima brutorum* (“concerning the souls of brutes”) is published. It extends the relationships of senses to the brain that had first been proposed by Galen. *See also* 170 CE MED.

Franciscus Sylvius writes *Praxeos medica idea nova* (“new idea in medicine”). He is one of the first physicians to

abandon the theory that illness is caused by an imbalance of the four humors (blood, black bile, yellow bile, and phlegm); instead, he thinks it is an imbalance between acids and bases. *See also* 400 BCE MED.

❀ Physics

Otto von Guericke’s *Experimenta nova Magdeburgica de vacuo spatio* (“new Magdeburg experiments concerning empty space”) describes his experimental work with a vacuum. *See also* 1660 CHEM.

1673

❀ Biology

Marcello Malpighi’s *De formatione pulli in ovo* (“on the formation of the chick in the egg”) describes the development of the embryo of chickens. *See also* 350 BCE BIO.

▀ Computers

Leibniz conceives a calculator that uses Pascal’s adding machine as its basis but that can also multiply and divide. He finally builds the device some 20 years later. *See also* 1645 TOOL; 1694 COMP.

John Ray

[b. Black Notley, England, November 29, 1627, d. Black Notley, January 17, 1705]

A prolific cataloger and writer, Ray introduced the first significant system of classifying plants and animals based on anatomy and physiology (it was superseded by the scheme of Linnaeus in 1735). Ray separated flowering plants into two groups, monocots and dicots, and was the first to use species as the fundamental unit of classification.

■ Construction

Claude Perrault translates Vitruvius into French with additional drawings and commentary. *See also* 25 BCE ENER.

Ⓔ Earth science

John Ray publishes *Observations Topographical, Moral and Physiological*, in which he argues for an organic origin for fossils. This is to some extent based on a sermon of his from 1650, which is also the core of his 1692 *Miscellaneous Discourses*. *See also* 1669 EAR; 1678 EAR.

▼ Energy

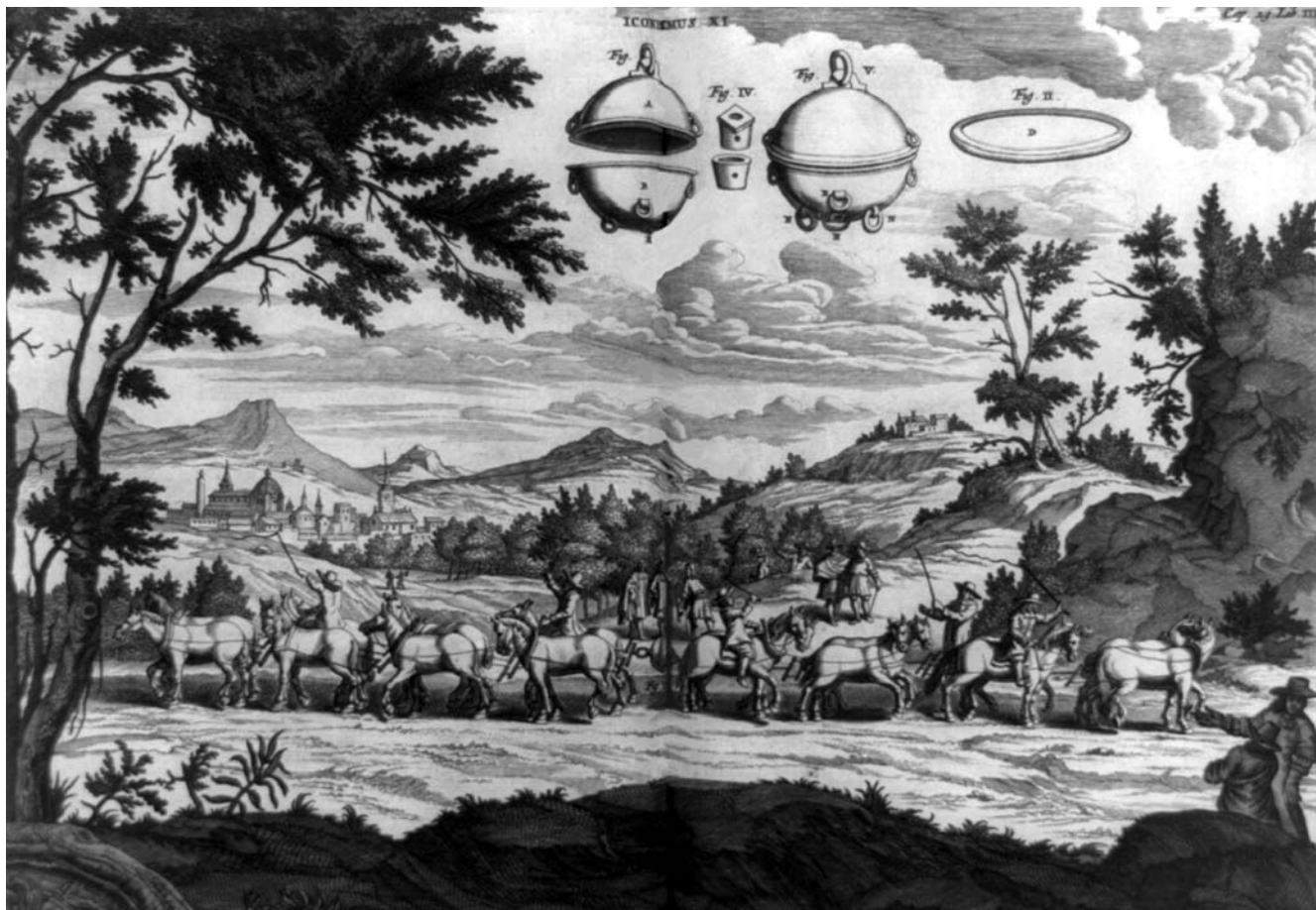
Christiaan Huygens builds a motor driven by the explosion of gunpowder. *See also* 1625 TOOL.

❖ Materials

Robert Boyle’s *Essays of the Strange Subtilty Determinate Nature and Great Efficiency of Effluvia* reveals his investigations and thought experiments concerning the masses of the smallest particles he can obtain of such materials as silver, gold, silk, and alcohol vapor. One of his concerns is explaining the poorly understood reactions of metals with oxygen, causing the resulting compound (or calx) to weigh more than the original metal. Boyle suspects particles from the flame that are small enough to penetrate glass. *See also* 1697 CHEM.

Σ Mathematics

About this time Leibniz discovers the celebrated series for $\pi/4$ that bears his name. He had been anticipated, however, by James Gregory in 1671. *See also* 1671 MATH.



THE MAGDEBURG SPHERE DEMONSTRATION Otto von Guericke is best known for demonstrating at Magdeburg (Germany) that a partial vacuum within two hemispheres kept together only by the force of air pressure produces a force so great that teams of horses cannot pull the hemispheres apart.

I Tools

Christiaan Huygens's *Horologium oscillatorium sive de motu pendulorum* ("the oscillation of pendulums") is the first fundamental work on scientific and practical mechanics, discussing the mathematics of time-keeping devices. In it, Huygens calculates the equivalent pendulum length and the laws of centripetal force. He proposes a form of pendulum clock based on the cycloid, a curve that, when used to enclose a pendulum on a string, adjusts the beat precisely as the amplitude

changes so that the beat remains the same. This turns out to be a clumsy adaptation and his previous pendulum clocks work better. *See also* 1656 TOOL; 1697 MATH.

Anton van Leeuwenhoek has by this time developed simple, single-lens microscopes with magnification up to 275 times (a device with a biconvex lens he grinds himself) and begins to send the English Royal Society letters on his discoveries. *See also* 1610 TOOL; 1677 BIO.



Anton van Leeuwenhoek

[b. Delft, Holland, October 24, 1632, d. Delft, August 26, 1723]

Leeuwenhoek made single-lens microscopes with exquisite lenses; with them he became the first person to see ciliated protists, which he called "animalcules" and "wretched beasties." He also discovered *Hydra*, rotifers, bacteria, and the sperm of dogs and other animals.

1674

★ Astronomy

Robert Hooke's *Attempt to Prove the Motion of the Earth* puts forward a theory of planetary motion based on the balance between centrifugal force and gravitational attraction from the Sun. *See also* 1687 PHY.

□ Chemistry

Tractatus quinque medico-physici ("five medico-physical treatments") by John Mayow reports on experiments in measuring the air consumed

by a mouse or a burning candle. Mayow is the first to note that the volume of air is reduced in respiration and that air must consist of two different gases. He determines that he can no longer ignite a flame (using a magnifying glass to concentrate sunlight) after one gas is depleted by burning or respiration. *See also* 1668 BIO.

❖ Materials

George Ravenscroft prepares a form of crystal with a very high index of refraction by adding black silex and lead oxide. *See also* 1723 PHY.

I Tools

Denis Papin [b. Coudraies, France, August 22, 1647, d. London, 1712] describes his experiments with air pumps in his memoir *Nouvelles expériences du vuide, avec la description des machines qui*

servent à le faire (“new experiments on the vacuum, with a description of machines to obtain it”). *See also* 1672 PHY.

1675

★ Astronomy

Giovanni Cassini discovers that the rings of Saturn are not a single flat disk surrounding the planet. The break in the rings he discovers is still known as the Cassini Division or Cassini Gap. *See also* 1656 AST.

Greenwich Observatory is founded by King Charles II. On March 4 he appoints John Flamsteed [b. Denby, England, August 19, 1646, d. Greenwich, England, December 31, 1719] as the first Astronomer Royal. *See also* 1667 AST; 1705 AST.

❖ Biology

Marcello Malpighi's *Anatome*

plantarum (“anatomy of plants”) is the first important work in plant anatomy based on microscopic observation. *See also* 1682 BIO.

Nicolaus Steno demonstrates that eggs are formed inside the dogfish before it gives birth to live offspring. He leaps to the correct conclusion that mammals have eggs. Around the same time Regnier De Graaf independently reaches the same conclusion, also on suspect evidence. *See also* 1672 BIO.

◊ Chemistry

Robert Boyle in *Reflections upon the Hypothesis of Alcali and Acidium* becomes the first to offer a qualitative test for acids and bases, defining acids as chemicals that turn syrup of violets red and alkalis as those that turn the same indicator green.

Σ Mathematics

Leibniz, independently from Newton, invents the differential and integral calculus about this time. On November 21, Leibniz becomes the first to use the modern notation $\int f(x) dx$ for an integral, improving on his notation of less than a month before. He also correctly finds the product rule for differentiation. *See also* 1666 MATH.

❖ Physics

Ole Christensen Römer [b. Århus, Denmark, September 25, 1644, d. Copenhagen, Denmark, September 19, 1710] measures the speed of light by measuring time differences of the eclipses of satellites of Jupiter. *See also* 1671 AST.

Newton delivers his *Discourse on Light and Colour* to the Royal Society. *See also* 1666 PHY; 1704 PHY.

Velocity of light

Most ancients, and even later scientists such as Johannes Kepler and René Descartes, believed the velocity of light to be infinite. Galileo thought otherwise and tried to measure light velocity with a method that had worked successfully for the measurement of the velocity of sound by Mersenne. Galileo and an assistant placed themselves on two hilltops some distance apart. Galileo flashed a light signal and the assistant responded by flashing a light signal in return as soon as he could see Galileo's light flash. Galileo then measured the time elapsed between the emission of his light signal and the return of the light signal from his assistant. Galileo soon realized that the elapsed time measured was independent of the distance to the assistant. Instead, the elapsed time was the time needed for the assistant to react to Galileo's signal.

The Danish astronomer Ole Römer solved the problem by using a much longer distance over which to measure the velocity of light. He noticed that when Earth and Jupiter were on the same side of the Sun, the eclipses of Jupiter's satellites by the

planet occurred a few minutes earlier than when the Sun was between Earth and Jupiter. Römer determined that it took 16 minutes longer for the light to travel when Earth was the farthest away from Jupiter than when Earth was closest. Römer deduced rightly that these 16 minutes were the time needed for the light to cover the distance between the closest and farthest positions of Jupiter. Römer calculated that the speed of light is 240,000 km (150,000 mi) per second.

Precise measurements of the velocity of light were made in the 19th century using specially designed apparatuses. These relied on the wave phenomenon of interference, where the crests of light waves of the same frequency either enhance each other or cancel each other. With lasers, it is possible to have light waves with exact frequencies, making this method extremely accurate. As a result, the speed of light in a vacuum, which is always constant, is, along with the second, the basis of our system of measurement. Since 1983 the meter has been defined as the distance light travels in 1/299,792,458 second; the speed of light is exactly 299,792,458 meters per second. Furthermore, since the American inch is defined by Congress as 2.54 times the centimeter, the speed of light is exactly 186,292.03 miles per second.

Progress in keeping time

In 1581 Galileo observed that a pendulum of a given length seemed to move through its cycle in a given amount of time no matter how long the swing (very nearly true for small swings as we now know). Many years later Galileo asked his son to build a clock using the pendulum as a regulator to improve the accuracy of a clock operated by a weight. But it was Christiaan Huygens a few years after that, in 1656, who made the pendulum clock practical. Although the simple pendulum does not swing at exact time intervals, Huygens modified the pendulum to solve this problem. He built the first grandfather's clock. It was a sort of miniature tower clock made accurate enough to keep time to the minute through use of the pendulum.

Around the same time, Robert Hooke was experimenting with springs. His discoveries led to clocks powered with springs instead of weights, making clocks portable. By the 18th century, clocks and watches that ticked the seconds were commonly available.

Mechanical clocks became more and more reliable and precise, but these clocks have limits. After World War II, scientists began to turn to other means to measure time. Isadore Rabi proposed an atomic clock in 1945 and the first was built by 1949. Atomic clocks use atoms that reliably vibrate millions of times a second. Even cheap silicon-chip wristwatches rely on hundreds or thousands of vibrations a second. As a result, time is regularly measured to almost unthinkable intervals today. A home computer uses a timer that may be anywhere from about 1.25 to 2.8 billion cycles a second. Without such precise measurement of time, computers would be unable to operate with anything like the speed and efficiency we have come to expect of them.

I Tools

Robert Hooke designs a compound microscope: An objective of very short focal length projects an enlarged image of the object, which is viewed with a magnifying eyepiece. See also 1610 TOOL.

Louis XIV tells the Académie des Sciences to study and describe machines. Jacques Buot [b. France, 1675, d. unknown] is charged with this mission and proposes to divide it in two parts, a theoretical discussion of principles and a discussion of how these principles are applied to

machines. Buot dies before being able to start the project, however. See also 1666 COMM; 1697 COMM.

Christiaan Huygens is the first to develop a practical spring-driven clock. He uses a spiral spring similar to that used in mechanical wound watches and clocks today. See also 1658 TOOL.

1676

★ Astronomy

Edmond Halley recognizes that close observations of the

times of transit of Mercury and Venus across the Sun can reveal the dimensions of the solar system. See also 1639 AST; 1761 AST.

❖ Biology

Naturalist Francis Willughby [b. Middleton, England, November 22, 1635, d. July 3, 1672] writes *Ornithologia* in Latin (translated by John Ray into English two years later). His systematic work on birds and fishes helps pave the way for Linnaeus's system. See also 1735 BIO.

❖ Communication

Sir Hans Sloane [b. Ireland, April 16, 1660, d. London, 1753] starts the British Museum.

Σ Mathematics

Leibniz discovers how to differentiate any integral or fractional power of x . See also 1675 MATH.

On June 13 Newton writes Leibniz a letter, now known as the *Epistola prior* ("earlier letter"), describing his work on infinite series. On October 24 Newton writes Leibniz a second letter, now known as the *Epistola posterior* ("later letter"); it includes an anagram in Latin describing his method of fluxions. See also 1666 MATH.

Traité des triangles rectangles en nombres ("treatise on numerical right triangles") by Bernard Frénicle de Bessy [b. Paris, 1605, d. Paris, January 17, 1675], published posthumously, contains a proof of Fermat's last theorem for $n = 4$, using Fermat's special method of infinite descent, a form of indirect proof. See also 1637 MATH; 1995 MATH.



Edmond Halley

[b. Haggerston, England, November 8, 1656, d. Greenwich, England, January 14, 1742]

Halley's contributions to science began as an astronomer, starting in 1676 when he traveled to Saint Helena to catalog the then unmapped stars of the Southern Hemisphere. In 1705 Halley wrote that comets travel in orbits that periodically bring them back to Earth's vicinity and correctly proposed that the comet of 1682 would return in 1758. In 1710, after comparing current positions of stars with those listed in Claudius Ptolemy's star catalog, Halley was the first astronomer to recognize that stars have motions of their own and that the Moon gradually changes its orbit.

Halley also studied Earth's magnetic field and weather, explaining the cause of monsoon winds and the relation between weather and barometric pressure. He invented the diving bell. Perhaps his greatest contribution to science, however, was persuading Newton to write the *Principia*.

❖ Medicine & health

Nehemiah Grew [b. Mancetter Parish, England, September 1641, d. London, March 25 1712] coins the term *comparative anatomy*. See also 1664 MED; 1682 BIO.

❖ Physics

Edmé Mariotte's *Essai sur la nature de l'air* ("on the nature of air") states Boyle's law, that for a gas, the product of volume and pressure is constant at a given temperature. In France, it is known as Mariotte's law. See also 1662 CHEM.

I Tools

Denis Papin starts a series of experiments with double-acting air pumps during the three years that he is employed by Robert Boyle. *See also* 1716 TOOL.

Robert Hooke, in a list of inventions that he intends to publish, includes the anagram “ceiiinossstuu,” which he reveals in 1679 to mean *ut tensio, sic vis* (“of the extension, so the force”). In other words, Hooke’s law — strain is proportional to stress in an elastic material. *See also* 1658 TOOL; 1679 TOOL.

Hooke invents a form of universal joint. *See also* 1664 TOOL.

1677

★ Astronomy

On November 7, Edmond Halley makes the first complete observation of a transit of Mercury. *See also* 1676 AST.

Biology

In November Anton van Leeuwenhoek confirms the discovery of sperm by Louis Dominicus Hamm. Unlike Hamm, who thinks sperm are evidence of disease, Leeuwenhoek concludes that sperm are the sources of reproduction, the larvae of humans (since Leeuwenhoek did not know of the mammalian egg, he did not propose fertilization). *See also* 1673 TOOL; 1680 BIO.

Chemistry

Johann Kunckel [b. Hutten (Germany), 1630, d. Dreisighufen (Germany), March 1703] describes an aqueous solution of ammonia. *See also* 1695 CHEM.

Earth science

Robert Plot [b. Borden, Kent, England, December 1640, d. 1696] in *The Natural History of Oxfordshire* describes, with illustrations, a “real bone now petrified”; he suspects it to be

an elephant bone brought to England by the Romans. It is later (1824) shown to be a dinosaur bone from a *Meglosaurus*, one of the first dinosaur bones known to science. *See also* 1822 EAR.

Mathematics

Leibniz correctly determines the quotient rule for differentiation.

1678

Construction

Military engineer Sebastian Le Prestre de Vauban [b. Saint-Léger, Nivernais, France, May 15, 1633, d. 1707] is appointed *Commissaire Général des Fortifications* for France. He develops a system of fortified fortresses to defend France against invasions.

Earth science

Athanasius Kircher [b. Geisa (Germany) May 2, 1601, d. Rome, November 28, 1680]

publishes his two-volume masterpiece, *Mundus subterraneus*, which describes fossils and other underground objects and spurs research on subterranean forces. *See also* 1673 EAR; 1691 EAR.

Food & agriculture

Chrysanthemums from Japan appear in Holland.

Dom Pérignon [b. Sainte-Menehould, France, 1638, d. Hautvillers Abbey, France, 1715] invents the method of making champagne from white wine by using a small amount of sugar to start a second fermentation in the cask and by storing the bottles so that sediment can be removed.

Mathematics

Giovanni Ceva [b. Milan (Italy), December 7, 1647, d. Mantua (Italy), June 15, 1734] proves the theorem named after him on the division of sides of a triangle (Ceva’s theorem).

The nature of light

The ancient Greeks were the first to propose theories of light and vision. Democritus suggested that atoms swarm from objects into the eye, the first particle theory. Other philosophers of Antiquity thought that some ray from the eye scanned the object. Neither theory explains why we don’t see in the dark. Arab writers were the first to suggest that light emanates from some objects (the Sun and stars, fire) and is reflected into the eye. But the nature of light itself was not obvious — it could be particles such as the ones Democritus suggested or it could be some other entity.

Some 17th-century scientists promoted a wave theory of light, as had Leonardo da Vinci earlier. Robert Hooke and Robert Boyle had observed the colors appearing in oil on water. By 1665 both had explained this by suggesting interference of the rays reflected from the two surfaces of the thin film of oil.

Newton rejected the wave theory of light, although his theory allowed for wavelike constructs. But Newton did not believe

that waves could cast sharp shadows. In principle, he was right. In reality, light does bend around sharp edges the way that waves do, but this could not be observed in Newton’s time. The amount of bending is too small. As a result, Newton believed that light must consist of particles.

Particle theories were popular in England in the 18th century, but a series of experiments by Thomas Young, starting in 1801, demonstrated that light is a wave phenomenon. Young showed convincingly that rays of light could interfere with each other, a phenomenon only possible for waves.

But Newton was not entirely wrong. In 1905 Albert Einstein showed that the photoelectric effect could be explained by assuming that light is composed of particles. In the photoelectric effect, electrons are knocked from a substance by light. Then Louis de Broglie suggested that entities recognized as particles could also be understood as waves. Experiments later confirmed this idea. Finally, physicists agreed that whether light behaves as a wave or as a particle depends on the property that is being measured.

❖ Physics

Christiaan Huygens writes *Traité de la lumière* ("treatise on light"), which explains his version of a wave theory for light. It is not published until 1690. *See also* 1665 phy; 1704 PHY.

1679

★ Astronomy

Catalogus stellarum australium ("catalog of southern stars") by Edmond Halley gives the locations and descriptions of 341 southern stars, the first time that stars observable from south of the equator have been cataloged. *See also* 1712 AST.

Giovanni Cassini prepares *Carte de la lune* ("chart of the Moon") for the Académie des Sciences, the best map of the Moon available to astronomers until the advent of photography. *See also* 1610 AST.

❖ Earth science

Jean Richer's *Observations astronomiques et physiques faites en l'île de Cayenne* ("astronomical observations made at the Cayenne Isle") describes the change in the period of the pendulum in different locations on Earth because of changes of gravity. *See also* 1672 EAR.

Edward Lhuyd [a.k.a. Lhwyd, b. Glan Ffraid, Cardiganshire, Wales, 1660, d. Oxford, England, June 30, 1709] publishes a description of a "flatfish"—the first written account of a trilobite (a marine arthropod of the Paleozoic). *See also* 1676 BIO; 1699 EAR.

❖ Food & agriculture

Denis Papin demonstrates his

"steam digester," a pressure cooker with a safety valve used for cooking bones. *See also* 1682 FOOD.

❖ Materials

Johann Kunckel invents the artificial ruby, a form of colored glass. He publishes the results of his experiments in *Ars vitraria experimentalis*. *See also* 1713 MATR.

Σ Mathematics

Leibniz introduces binary arithmetic by showing that every number can be represented by the symbols 0 and 1 only (in a letter to the Jesuit Joachim Bouvet). *See also* 1937 COMP.

❖ Physics

Robert Hooke suggests in a letter to Newton that gravitational attraction varies inversely with distance from the Sun and asks if this does not imply elliptical orbits for planets; Newton does not reply. *See also* 1665 phy; 1680 PHY.

I Tools

Robert Hooke's *De potentia restitution, or Of a Spring* reveals the meaning of his 1676 anagram, which we now know as Hooke's law of the spring: Force is proportional to extension. *See also* 1676 TOOL.

1680

★ Astronomy

Old Moore's Almanack is started by Francis Moore [b. Bridgnorth, England, 1657, d. 1715]. It becomes later known as *Vox stellarum* ("voice of the stars"). *See also* 1497 COMM; 1732 EAR.

❖ Biology

Giovanni Alfonso Borelli's posthumous *De motu animalium* ("on the motions of animals," a second volume published in 1681) treats the movements and contractions of the muscles and includes his explanation of the power of a torpedo fish to produce shocks as a result of rapid contractions of a muscle, now known as the electric organ. Borelli also states that human muscles are not strong enough in proportion to human weight for flight similar to that of birds. *See also* 1671 BIO.

Leeuwenhoek is the first to see yeast cells. *See also* 1677 BIO; 1683 BIO.

I Chemistry

Robert Boyle's *The Aerial Noc-tiluca* describes phosphorus independently from Hennig Brand's discovery. *See also* 1669 CHEM.

❖ Medicine & health

Marcello Malpighi undertakes the first scientific study of fingerprints. *See also* 1823 COMM.

❖ Physics

Newton, spurred by boasts from Robert Hooke that he has solved the riddle of planetary motion, calculates that an inverse-square law of attraction to the Sun will produce an elliptical orbit. *See also* 1679 PHY.

I Tools

Clocks are equipped with hands to show minutes. *See also* 1675 TOOL; 1704 TOOL.

The centrifugal pump is invented. *See also* 1698 ENER.

→ Transportation

Newton proposes that a jet of steam can be used (like a rocket) to power a carriage, an idea now considered one of the precursors of the jet engine. *See also* 1650 TRAN.

1681

❖ Materials

A lime kiln is established in the Pennsylvania colony, one of the first chemical industries in what will become the United States.

→ Transportation

In May, Pierre-Paul Riquet's Canal du Midi connecting the Mediterranean Sea and the Bay of Biscay in the Atlantic Ocean is opened by Louis XIV in France, although it will not be finished until 1692. *See also* 1666 tran; 1692 TRAN.

1682

★ Astronomy

Edmond Halley observes the "Great Comet" that will be named after him after he correctly predicts (in 1705) that the comet will return in 1758. *See also* 1664 AST; 1705 AST.

❖ Biology

Nehemiah Grew's *The Anatomy of Plants* describes the different types of tissues making up stems and roots, and identifies the male and female parts of flowering plants. Grew shows that plant tissues are composed mostly of small chambers, or cells. *See also* 1675 BIO; 1694 BIO.

John Ray in *Methodus plan-tarum nova* ("new method for plants") introduces a classification scheme for plants, dividing them into monocots and dicots

on the basis of the number of their seed leaves. Although Ray invents the words *monocotyledon* and *dicotyledon*, he will not use them in print until the second edition (1703). *See also* 1686 BIO.

Communication

Leibniz starts *Acta eruditorum*, the first learned journal on the continent of Europe. It is in Latin and continues to be published until 1776. *See also* 1665 COMM.

Energy

John Clayton [b. England, 1657, d. 1725] discovers coal gas, a gas similar to natural gas (methane) formed by distillation of coal. *See also* 1659 ENER; 1739 ENER.

Food & agriculture

Denis Papin describes the use of his “steam digester,” first demonstrated in 1679. It is a pressure cooker that he uses to produce gelatin from animal bones. He also fits the device with a safety valve invented by himself. *See also* 1679 FOOD.

1683

Biology

Anton van Leeuwenhoek observes bacteria, which will not be seen by other scientists for more than a century. *See also* 1680 BIO; 1786 BIO.

Food & agriculture

The Siege of Vienna by the Turks leads indirectly to the development of the typical Viennese coffeehouse (the Viennese learned to drink coffee from the Turks) and also to the introduction of the lilac into western Europe — it grows wild in eastern Europe.

Mathematics

Seki Kōwa [b. Fujioka, Japan, March 1642, d. Edo (Tokyo), October 24, 1708] produces a mathematical treatise with the first known explanation of the concept of determinants, functions that assign a numerical value to a square array of symbols. *See also* 1693 MATH.

1684

Astronomy

Giovanni Cassini discovers Dione and Thetys, satellites of Saturn. *See also* 1672 AST.

Ole Römer invents the transit telescope, perhaps following a design from Abbé Picard, and installs one in the window of his house in Copenhagen. *See also* 1667 AST.

Communication

Robert Hooke describes a system of visual telegraphy. *See also* 1792 COMM.

Mathematics

Leibniz’s “A New Method for Maxima and Minima as Well as Tangents, Which Is Impeded Neither by Fractional nor by Irrational Quantities, and a Remarkable Type of Calculus for This” is the first published account of differential calculus. Its six pages are so dense, however, that few can understand them. *See also* 1676 MATH.

Physics

Robert Hooke boasts to Christopher Wren and Edmond Halley that he has found the laws governing the movement of the planets. Wren correctly perceives that Hooke is wrong and offers a prize to anyone who can solve the problem. Halley visits Newton to ask what planetary orbits would be if the

planets are attracted to the Sun according to an inverse-square law, to which Newton immediately replies, “An ellipse, for I have calculated it.” This leads Halley to encourage Newton to write out his ideas, which become the *Principia*. *See also* 1680 PHY; 1687 PHY.

1685

Construction

After two other designers fail to solve problems that arise in building a bridge across the Seine between the Tuileries Palace of Louis XIV and the south bank of the Seine, François Roman [b. Belgium, 1646, d. 1735] develops a new technique in bridge building. First he sinks a large barge loaded with stone on a dredged site, forming a caisson (from the French *caisse*, or box) in which the pier is built. The final bridge, known as the Pont Royal, earns Roman the label “first engineer of the century.” *See also* 1611 CONS; 1772 CONS.

Mathematics

John Wallis’s *De algebra tractatus* (“a treatment of algebra”) contains the first publication of Newton’s binomial theorem and an early way to represent complex numbers geometrically. *See also* 1669 MATH.

1686

Biology

John Ray’s *Historia plantarum* (“history of plants”) starts to be published (it will be complete in three volumes in 1704). It describes 18,600 plant species, laying the groundwork for Linnaeus. It introduces the first definition of species, based on common

descent, into science. *See also* 1682 BIO; 1735 BIO.

Francis Willughby writes *De historia piscium* (“on the history of fish”).

Communication

Entretiens sur la pluralité des mondes (“conversations on the plurality of worlds”) by Bernard le Bovier de Fontenelle [b. Rouen, France, February 11, 1657, d. Paris, January 9, 1757] popularizes the theories of Descartes. *See also* 1664 AST; 1690 AST.

Earth science

Edmond Halley proposes that the regular pattern of winds is produced by cold air from the poles moving under warm air at the equator and pushing it up. *See also* 1735 EAR.

Mathematics

Leibniz describes the integral calculus in print for the first time in an issue of *Acta eruditorum*. *See also* 1684 MATH.

Jacques (Jakob) Bernoulli writes on the parallels between algebra and logic and on probability. *See also* 1683 MATH; 1688 MATH.

Jacques (Jakob) Bernoulli

[b. Basel, Switzerland, December 27, 1654, d. Basel, August 16, 1705]

The first member of the Bernoulli family to become famous, Jacques learned calculus from Leibniz and applied the new techniques in the investigation of various curves and infinite series. He was the first to publish work using polar coordinates although Newton had used them earlier without publishing. Bernoulli also wrote the first account of probability theory, including permutations and combinations.

Newton's *Principia*

The greatest breakthroughs in physics occur when someone understands that apparently different phenomena have the same underlying cause. One of the great unifiers was Isaac Newton. Newton was the first to demonstrate that the falling of objects toward Earth's surface, the motion of the Moon around Earth, the motion of planets around the Sun, and the odd trajectories of the comets are all governed by one law: the law of universal gravitation.

However, the idea of universal gravitation only became clearly formed in Newton's mind in the 1680s, when he was preparing the manuscript for his *Principia*. He had had a first inkling of this idea some 20 years earlier. At the end of his life, Newton related that he started wondering whether one could consider the Moon as falling toward Earth when he observed an apple falling from a tree.

In 1666 Newton studied circular motion. He found that the force acting on a circling body is inversely proportional to the square of the distance of the body from the point around which it rotates. This result was also found by Christiaan Huygens, who published it in his *Horologium oscillatorium* in 1673.

Newton tried to apply this concept to the Earth-Moon system and to the planets. He realized that the motion of the Moon could be viewed as having two components. One of these components is the Moon's fall toward Earth; the other is its motion in a straight line. Both motions occur at once, resulting in the nearly circular path of the Moon. Its path is curved toward Earth because of Earth's gravitational attraction. In the absence of Earth, the Moon would move on a straight line.

Newton first determined how much the Moon's motion deviates from a straight line. He then compared the pull acting on the Moon with the pull acting on a body on the surface of Earth. Newton determined that a body dropped at Earth's surface will fall 490 cm (16 ft) in the first second. He then found that the Moon deviates from a straight path — and thus "falls" toward Earth — over 366 cm (12 ft) during one hour. If the Moon were at the surface of Earth it would fall 490×3600 cm (16 × 3600 ft) in an hour. Now Newton compared this with the inverse-square law that he had derived for rotating bodies on Earth. Since the Moon is about 60 Earth radii from Earth, it would be accelerated toward Earth 60^2 (3600) times slower, which is approximately the case based on observation. (He actually found this factor to be 4000; the error was caused because Newton used an incorrect value for the size of Earth.)

Newton came to the conclusion that a force inversely proportional to the square of the distance from a body to its center of rotation keeps the Moon and planets in their orbits. In 1645 the French astronomer Ismael Boulliau had also suggested, without

giving proof, that a central force inversely proportional to the square of their distance from the Sun might keep the planets in their orbits.

For a period after 1666, however, Newton turned his attention to optics and chemistry. In 1679 he again became interested in planetary orbits when Robert Hooke asked him to demonstrate that a planet would move in an elliptical orbit when subjected to a central force inversely proportional to the square of its distance from the Sun. Newton found a mathematical proof, but never forwarded it to Hooke.

Christopher Wren and Edmond Halley were also investigating the problem, but neither could solve it. In 1684 Halley, who was the clerk of the Royal Society, visited Newton and asked him what he thought the orbit of a planet might be under an inverse-square law. Newton immediately replied, "An ellipse, for I have calculated it." Halley asked him to produce his paper with the calculations. Newton replied that he had mislaid this paper, but that he would start over with his calculations.

A few months later Halley received a paper from Newton called *De motu corporum in gyrum* ("on the motion of revolving bodies"), which Halley presented to the Royal Society. Halley's interest spurred Newton to develop his ideas further. Over the next two and a half years he wrote the *Principia*. Halley edited the sections of the manuscript Newton sent him and saw it through the press, at one time employing two printers to speed up the process. Because the Royal Society had no funds available at the time, Halley paid for the printing of the *Principia* from his own pocket.

At an early stage of the writing of the *Principia*, Hooke discovered that Newton did not mention him in connection with the inverse-square law, which he believed he had discovered prior to Newton. Hooke, who had never given a mathematical proof, attacked Newton, and the dispute over the priority of the discovery furthered the bitter feud that had long existed between the two scientists.

The *Principia* was published late in 1687. Unlike Galileo, who wrote his books in Italian, Newton wrote the *Principia* entirely in Latin. Although he had developed calculus during earlier years, he drafted the book using classical geometry — as was the custom at that time — to tackle physical problems.

Book I of the *Principia* contains Newton's three laws of motion and a discussion of orbital motion. Book II deals with the motion of fluids and attempts to prove that the vortex model proposed by Descartes cannot explain the motion of celestial bodies. Book III, *The System of the World*, contains the proposition that gravity is proportional to mass. In this book, Newton discusses applications of his theory to planetary orbits. He shows how his theory accounts for the irregularities of the motion of the Moon as well as the trajectories of comets.

* Physics

Edmé Mariotte's *Traité mouvement des eaux et des autres corps fluides* ("the motion of water and other fluids") is published posthumously. *See also* 1676 PHY.

Newton presents the manuscript of the first volume of the *Principia, De motu corporum* ("the motion of bodies"), to the Royal Society. *See also* 1684 phy; 1687 PHY.

1687

* Astronomy

Gottfried Kirch [b. Guben (Germany), December 18, 1639, d. Berlin, July 25, 1710] discovers the variability of the star Zeta Cygni. *See also* 1669 AST; 1704 AST.

■ Construction

Venetian gunfire sets off ammunition stored by the Turks in the Parthenon, causing an explosion that destroys the roof and wrecks much of the rest of the building. *See also* 432 BCE CONS.

⊕ Earth science

Newton explains exactly how gravitational forces of the Moon and Sun combine with the rotation of Earth to raise ocean tides. *See also* 300 BCE EAR.

* Physics

In September Newton's *Philosophiae naturalis principia mathematica* ("the mathematical principles of natural philosophy"), known as the *Principia*, establishes Newton's three laws of motion and the law of universal gravitation. The book also becomes the basis for the further develop-

ment of theoretical mechanics for the next 200 years. *See also* 1665 PHY.

I Tools

Guillaume Amontons [b. Paris, August 31, 1633, d. Paris, October 11, 1705] invents a hygrometer, one of several tools used to measure humidity in air.

↗ Transportation

In his *Systemate mundi* ("system of the world"), the third volume of the *Principia*, Newton describes how to launch an artificial satellite from a high mountaintop with a cannon and provides a diagram illustrating the method. *See also* 1957 TRAN.

1688

Σ Mathematics

Sometime before this date Lloyds of London is founded, showing that business people were already calculating probabilities. *See also* 1686 MATH; 1689 MATH.

I Tools

The French army introduces bayonets that are attached to muskets, replacing French bayonets used for past 30 years that fit into the barrels of the guns.

1689

Σ Mathematics

Jacques (Jakob) Bernoulli writes on infinite series and also discovers the law of large numbers, which states that the number of occurrences of an event with a given probability will approach the ratio described by that probability

as the number of occurrences increase. *See also* 1688 MATH; 1713 MATH.

1690

* Astronomy

Christiaan Huygens writes *The Discovery of Celestial Worlds: Theories about Inhabitants, Plants, and Products of Planetary Worlds*. It speculates that the universe is populated with "so many Suns, so many Earths," and that life exists not only on Earth but also on planets orbiting other stars.

⌚ Communication

Essay Concerning Human Understanding by John Locke [b. Somerset, England, August 29, 1632, d. High Laver, Essex, England, October 28, 1704] argues that all knowledge of man comes from experience and sensations only.

❖ Ecology & the environment

William Penn, founder of Pennsylvania colony, decrees that settlers preserve one acre of trees for every five acres they clear.

↗ Energy

Denis Papin describes an apparatus in which the condensation of steam in a cylinder creates a vacuum in *Nova methodus ad vires motrices validissimas levi pretio comparandas* ("New method of obtaining very great moving forces at small cost"). *See also* 1663 ENER; 1698 ENER.

🍴 Food & agriculture

During the 150 years preceding this date, the Netherlands acquires 167,264 hectares (413,318 acres) of new land

for farming by diking and draining land covered by the sea.

❖ Materials

The General Court of Massachusetts issues what becomes the first widely used paper currency in North America, known as old colony or charter bills. 1658 MATR; 1992 MATR.

♥ Medicine & health

French surgeon Pierre Dionis [b. 1658, d. 1718] publishes a book on human anatomy describing the functioning of the stomach and intestines. *See also* 1822 MED.

1691

⊕ Earth science

John Ray's *The Wisdom of God Manifested in the Works of Creation* is the first to suggest that fossils are the remains of animals from the distant past. It establishes Ray as the leader of the natural history revival in England. *See also* 1678 EAR; 1699 EAR.

Σ Mathematics

Méthode pour résoudre les égalitez ("method for resolving equalities") by Michel Rolle [b. Ambert, France, April 21, 1652, d. Paris, November 8, 1719] contains, without proof or fanfare, the theorem of the calculus named after him. It is an essential theorem that states that a continuous curve that possesses tangents everywhere must have a tangent parallel to the x axis between any two points where the curve crosses the x axis. *See also* 1686 MATH.

Recognizing the power of steam

That steam can exert power was known by the ancient Greeks. But as was the case with many of their discoveries, they applied this knowledge only to toys. Heron of Alexandria built such a toy, the aelopile. It consisted of a spherical vessel fitted with two jets pointing in opposite directions; when steam was admitted to the sphere, it escaped through the two jets, causing the sphere to rotate.

During the Renaissance there was renewed interest in the power of steam. Although it is not true that James Watt saw the lid rising on a pan of boiling water and got the idea for the steam engine, someone surely did. Noticing that steam in an enclosed place has the power to lift objects is the first step toward building a steam engine. Alternately, lifting with steam and letting the steam cool back into water is the simplest form of a steam engine. The natural philosopher Giambattista della Porta recognized the two advantageous aspects of steam: By creating pressure, steam could, for example, force water out of a vessel, or by condensing, it could create a vacuum. He demonstrated the latter property by filling a flask with steam and plunging it underwater. As the steam cooled and condensed, a vacuum formed in the flask, drawing in water.

It was Denis Papin, who had studied medicine and physics, who first thought of using steam to move a piston in a cylinder to deliver work. He started working for the French Academy of Science and became the assistant of Christiaan Huygens, the Dutch astronomer who was one of the founding members of the academy. Huygens was then experimenting with air pumps and with a gunpowder engine. One of Huygens's aims was to create a vacuum by exploding gunpowder in a cylinder with a piston. The piston would shoot to the top of the cylinder and thus create a vacuum.

Papin, who also experimented with such devices, found that

steam was not only a much better agent to create a vacuum, but could be used to deliver work. His simple steam engine of 1690, also called Papin's cylinder, consisted of a cylinder closed at the bottom, containing water, and sealed off by a movable piston. When the water boiled, the piston rose, and when the steam condensed, creating a vacuum, it descended.

Papin, being primarily a scientist — he even taught mathematics at a German university — never did build a practical engine that could deliver mechanical work. People less removed from industry, such as the British engineer Thomas Savery and later Thomas Newcomen, devised the first machines that put steam to work.

The steam engines of the 1700s, when practical engines were first built, were all improvements on the idea behind Papin's simple engine. The cylinder and piston later became the essential components of steam engines, but the first device that used steam for delivering work did not have a piston. It was invented by the British engineer Thomas Savery and was patented in 1698. His design, a water pump used for pumping water out of mines, and therefore called the Miner's Friend, made use of both the ability of steam to exert pressure and to create a vacuum. First steam from a boiler was admitted to a vessel; after the steam supply valve was closed, it was condensed by a spray of water. The created vacuum in the vessel raised water through a one-way valve; when the vessel was filled, steam was admitted into it again, forcing the water upward through a second one-way valve. Savery produced a working model of his steam pump, but there are no records of such engines being used in mines. It is known that one engine worked at the York Buildings in London, pumping water from the Thames. Its use was abandoned because of a number of technical difficulties — the main one being that the precision workmanship and strength of materials at the time were insufficient for this type of machine.

♥ Medicine & health

Clopton Havers [b. Stambourne, England, c. 1655, d. Willingale, England, April 1702] publishes the first complete textbook on the bones of the human body. *See also* 1676 MED.

I Tools

The *Collection for Improvement of Husbandry and Trade* starts publication in England. It is a journal for artisans.

1692

Σ Mathematics

Leibniz introduces the terms *coordinate*, *abscissa*, and *ordinate* to describe the numbers (x, y) used to identify points in analytic geometry. *See also* 1627 MATH.

→ Transportation

Pierre-Paul Riquet's Canal du Midi, then known as the Languedoc Canal, is finally completed 12 years after Riquet's death. It is 290-km

(180-mi) long, needing 100 locks to carry it high above the Atlantic and the Mediterranean, which it connects. It includes a 165-m (540-ft) tunnel and three aqueducts over rivers along the way. *See also* 1681 TRAN; 1761 TRAN.

The 74-km-long (46-mi-long) French Canal of Orléans, promoted by Jean-Baptiste Colbert [b. 1619, d. 1683], who was also behind the Canal du Midi (Languedoc Canal), is completed and connected to the Loire River. *See also* 1681 TRAN.

1693

↗ Biology

John Ray's *Synopsis animalium quadrupedem et serpentini* ("synopsis of four-legged animals and serpents") introduces the first important classification of animals. It follows Aristotle's divisions into "blooded" and "bloodless" and correctly classifies whales as mammals. *See also* 1555 BIO; 1735 BIO.

The canal age

From earliest civilized times people built canals for irrigation. Anyone who has ever portaged even a small canoe from one stream or lake to another has envisioned a canal replacing his or her trail, so the canal idea was extended from providing water for crops to providing a highway for boats. The technology of a short, level canal between two bodies of water at the same height is as simple as can be — all you need is enough people to dig. In China, where finding enough people has never been a problem, transportation canals became important as early as the third century BCE. In the West, early transportation canals were developed primarily to shorten sea routes, but Chinese canals connected river systems and bound the people together. Terrain was one of the reasons Chinese canals got a head start on European ones. Many of the obvious places that needed connecting in Europe were separated by rocky hills or even mountains. Where it was clear that a canal could help shipping, as across a narrow peninsula or between nearby bodies of water, Westerners built or at least planned to build canals.

Intervening changes in land height and different water levels posed problems. Canals could be and were built in sections; boats were hauled up artificial rapids from one level section to another or even on land around barriers. In the tenth century in China, the canal lock, or pound lock, was developed to permit better connections. Such locks enabled the Chinese Grand Canal to rise from sea level to 42 m (138 ft) above. Several hundred years later the idea of the lock was taken up by the West at a time when many Chinese influences began to be felt in Europe (paper and gunpowder are the best known), although by that time locks and canals had passed their greatest days in China.

With the coming of locks, certainly known in Italy in the 15th century, European canal building began to enter its great period of expansion. Canal building spread in much the same pattern as the Black Death had earlier, although more slowly and, of course, with more positive results. France began to build major canals in the 17th century, while England and northern Europe became more active in the 18th. In France, the grand project of connecting the two French coasts (Atlantic and Mediterranean) was active intermittently for more than 150 years before becoming reality in 1681. Other major French canals were built around this time as well. The French canals, like most canals that were to follow, were too narrow for much sailing. Instead, ships were towed through the canals by animals, such as mules, that walked on paths along the banks.

The French canals inspired the English. Notably, the Duke of Bridgewater, Francis Egerton, having seen French canals while on the Grand Tour, hired surveyor James Brindley, who had previous

planned a canal but never built one, to construct a canal between coal mines on his estate at Worsley and the booming industrial center at Manchester. The Bridgewater (Worsley) Canal opened for traffic in 1761 and for some historians this date marks the beginning of the Industrial Revolution, for the cheap coal, available year-round, fueled all the factories of Manchester. Brindley became much sought after as a canal designer by various commercial enterprises.

By 1792 there were no less than 30 different canal schemes competing for capital financing in England. The craze spread back from England to the Continent, inspiring canal projects in Scandinavia, Russia, the Low Countries, Germany, and even back to the country of England's inspiration, France. Not only were new canals built, but also existing rivers were converted into canals by building walls and leveling river bottoms.

By the end of the 18th century or the beginning of the 19th, canal building had spread far beyond Europe. Canals were a feature of life in the United States and Canada in the early 19th century. Egypt, with an early history of canal building that had lapsed two millennia earlier, linked Alexandria with the navigable Nile using a canal built by 350,000 peasants, working largely with their bare hands.

Although the railroad was to replace the canal for inland commercial hauling in the 19th century, there were still two great ship canals needed, projects to carry goods beyond the capacity of rails. Ships carrying goods or passengers between Europe and the East Coast of North America, the two main commercial centers of the world of the 19th century, had to pass around either Africa or South America to reach the lucrative and populous Asian continent. Fairly short canals, albeit through difficult terrain, could shorten such journeys by thousands of kilometers. This solution was reached for Africa by the Suez Canal, between the Mediterranean and Red seas, which opened in 1869, although it was not commercially viable until the British deepened and widened it late in the 19th century. The Panama Canal connected the Atlantic and Pacific oceans in 1914. Both great canals were among the most colossal engineering enterprises of the time. A glance at the map of the world shows that these two canals finish off the only available opportunities to improve linkages so dramatically with relatively short waterways.

Although canals will continue to be built for special purposes, the great age of canal building is over. Although the age is past, canals delight people still. Devoid of serious shipping, remaining inland canals boast pleasure boats and even special canal excursions. A few canals — Panama, Suez, St. Lawrence Seaway — continue to have great economic presence, but for the most part canals reflect a more gracious period for shipping that passed well over a hundred years ago.

Botanist Charles Plumier [b. Marseilles, France, April 20, 1646, d. near Cadiz, Spain, November 20, 1704] publishes *Description des plantes de l'Amérique* ("description of American plants"), which describes over 50 ferns as well as other plants. *See also* 1686 BIO; 1704 BIO.

Earth science

John Ray's *Three Physico-Theological Discourses* sums up his theory of the history of Earth. The three are the Creation, the Deluge, and the Conflagration (a predicted end for Earth). *See also* 1654 EAR.

Mathematics

John Wallis's *Opera mathematica* ("mathematical works"), Volume II, contains the first complete printed statement of Newton's "method of fluxions," essentially the calculus. *See also* 1676 MATH; 1736 MATH.

Leibniz rediscovers the concept of determinants and communicates it to Antoine de L'Hospital in a series of letters, which will not be published until 1850. *See also* 1683 MATH.

1694

Biology

De sexu plantarum epistola ("letter on the sex of plants") by Rudolph Jacob Camerarius [b. Tübingen (Germany), February 12, 1665, d. Tübingen, September 11, 1721] clearly distinguishes the male and female reproductive organs in plants. *See also* 1682 BIO.

Communication

Thomas Corneille [b. Rouen, France, August 20, 1625, d. Les

Andelys, France, December 8, 1709] compiles *Le dictionnaire des arts et des sciences* ("dictionary of arts and sciences"). It is published as a supplement to the dictionary of the French Academy. The Corneille work is one of the predecessors of modern encyclopedias. *See also* 1701 COMM.

Computers

Leibniz completes a calculating machine. Called the Stepped Reckoner, it uses the binary representation of numbers for its operation and can store a multiplicand in a register, thus eliminating the need of successive additions to effect multiplication. The calculator can also divide and extract square roots. *See also* 1673 COMP; 1820 COMP.

Mathematics

Philippe de La Hire [b. Paris, March 18, 1640, d. Paris, April 21, 1718] publishes his *Traité des épicycloïdes et leur usage en mécanique* ("treatise on epicycloids and their use in mechanics"). An epicycloid is a curve formed as a point on a circle rolls around the outside of another circle without slippage.

Medicine & health

After a bad year causes vintners in the vicinity of Ulm (Germany) to sweeten their wines more than usual, there is an outbreak of illness among wine drinkers. Eberhard Gockel, city physician of Ulm, traces it to the use of an oxide of lead as the sweetener. *See also* 1697 MED.

1695

Chemistry

Nehemiah Grew isolates mag-

nesium sulfate — commonly known as Epsom salts — from spring water. *See also* 1677 CHEM; 1702 CHEM.

1696

Astronomy

William Whiston [b. Norton, Leicestershire, England, December 9, 1667, d. Lyndon, Rutland, England, August 22, 1752] publishes *A New Theory of the Earth*, which attributes natural causes to major Biblical events. For example, he proposes that a comet striking Earth caused Noah's Flood. *See also* 1682 AST.

Biology

Arcana naturae ("mysteries of nature") by Anton van Leeuwenhoek discusses his discovery of "animalculæ" (microorganisms, chiefly those now known as protists). *See also* 1683 BIO; 1702 BIO.

Mathematics

Analyse des infiniment petits ("analysis of the infinitely small") by Marquis Antoine de L'Hospital [b. Paris, 1661, d. Paris, February 2, 1704] is the first textbook on differential calculus and remains influential for the next century. It contains "L'Hospital's rule" (bought by L'Hospital from Jean Bernoulli, who discovered it in 1694). The rule is a basic tool in calculus for evaluating the quotient of two functions when that quotient appears to produce a meaningless expression, such as 0/0. *See also* 1693 MATH; 1736 MATH.

1697

Chemistry

Georg Ernst Stahl [b. Ansbach

(Germany), October 21, 1660, d. Berlin, May 14, 1734] introduces the concept of phlogiston as the cause of burning and rusting, basing his idea on the 1669 idea of an "oily earth" that had the same role in the theories of Johann Joachim Becher. *See also* 1669 CHEM.

Communication

The French Académie des Sciences is reorganized. Bernard de Fontenelle becomes its secretary. *See also* 1666 COMM; 1704 COMM.

Mathematics

Jean (Johann) Bernoulli proposes the problem of the brachistochrone — finding the path of quickest descent. It is solved by Newton, L'Hospital, Leibniz, and himself (incorrectly at first). The solution is a curve called the cycloid, which is formed by a point on a circle as it rolls without slippage on a straight line. *See also* 1673 TOOL; 1718 MATH.



Jean (Johann) Bernoulli
[b. Basel, Switzerland,
August 6, 1667, d. Basel,
January 1, 1748]

Jean became a rival of his brother Jacques, especially since they worked on many of the same problems in the newly invented calculus. Jean is usually credited with inventing the calculus of variations, the technique for finding a function that produces a maximum or minimum.

Phlogiston

The question of what fire really is has intrigued people since ancient times, but not until the Renaissance did scientists offer explanations for the phenomenon. Classical Greeks thought that fire is an "element" no more explicable than earth, water, or air.

Robert Boyle found, however, that fire depends on air. If one removes air in a vessel, combustion cannot take place. He also found that air is required for the respiration of small animals and for the production of oxides from metals by heating them. In this process chemical changes caused by heating a substance to a temperature below the melting point (calcination) results in a compound called a *calx*.

Around this time, however, chemists in Germany formulated a theory of combustion that did not require air. Johann Joachim Becher believed that combustible matter contains "oily earth," a substance released during combustion. Georg Stahl renamed this substance *phlogiston*. With the phlogiston theory these chemists could explain not only combustion but also the reverse of calcination, reduction. According to this theory, if calx of lead is brought into contact with charcoal and heated, the phlogiston flows from the charcoal into the calx of lead, changing it to metallic lead. Because charcoal burns so well, it was believed to contain a lot of phlogiston.

One of the first indications that something was amiss with the

theory was evidence that metals gain weight upon calcination. Clearly, this contradicted the idea that upon calcination, phlogiston leaves the metal. Chemists saved the phlogiston theory by assuming that the substance had "negative weight."

Around the same time Joseph Priestley experimented with heating calx of mercury and found that it produces "air" with special properties. (The word *gas* had entered English in 1658 but was not common yet; Priestley used it sometimes, but felt he had to explain it.) If one introduces a candle into this "air", the candle burns vigorously. A mouse shut in a jar with it lives longer than one shut in a jar filled with ordinary air. Priestley believed in phlogiston, so he tried to explain this result with the phlogiston theory. Priestley called this "air" *dephlogistonated air*. He believed that air has phlogiston added to it by fires and by breathing.

Antoine Lavoisier discovered in 1772 that phosphorus and sulfur absorb a portion of air when burning instead of expelling something. Lavoisier also discovered that the reduction of calx of lead releases large quantities of "fixed air," air that does not sustain life or combustion (now known as carbon dioxide). That is, reducing a calx to a metal expels something, it does not absorb something. These results, and also the results of other experiments, led Lavoisier to formulate a theory of combustion that superseded the phlogiston theory. Lavoisier had realized that "dephlogistonated air," a gas that he subsequently termed oxygen, was responsible for the combustion of materials.

Heart Medicine & health

Eberhard Gockel publishes *A Remarkable Account of the Previously Unknown Wine Disease*, about his discovery that a local epidemic in Ulm (Germany) has been caused by using a lead-based sweetener in wine. See also 1657 MED.

Tools

Inventor Christopher Polhem [b. Visby, Gotland Island, Sweden, December 18, 1661, d. Tingstäde, Sweden, August 30, 1751] establishes a mechanical laboratory for the study of simple machines, or machine elements, which he terms the "mechanical alphabet." The different machine elements are studied with the help of mechanical models. He spe-

cializes in new mining tools and also builds a factory to produce them. See also 1675 TOOL; 1708 TOOL.

Transportation

Paul Hoste [b. Ponte de Veyle, Bresse, France, May 19, 1651, d. Toulon, France, February 23, 1700] publishes *Théorie de la construction des vaisseaux* ("theory of ship construction"), in which he describes designs of ships for which the center of gravity lies higher than the hydrostatic center of force.

1698

Construction

Henry Winstanley [b. 1644, d. off Plymouth, England,

November 1703], after two years' labor, succeeds in building the first lighthouse on the Eddystone Rocks off Plymouth, England. At 18 m (60 ft) or 24 m (80 ft), depending on whose account you follow, it is not high enough. Spray continually puts out the 60 tallow candles that are the source of the light. See also 1611 CONS; 1699 CONS.

Energy

The Miner's Friend, invented by Thomas Savery [b. Shilstone, England, c. 1650, d. London, May 1715], designed to pump water from coal mines, is patented. It will become the first practical machine powered by steam. See also 1702 ENER.

1699

Construction

Henry Winstanley builds the Eddystone Light 12 m (40 ft) taller to escape the ocean spray that puts out the candles that are the source of the light. See also 1698 CONS; 1703 CONS.

Earth science

Edward Lhuyd's natural history of the Celtic parts of Britain includes the first illustration of ichthyosaur fossils. See also 1691 EAR; 1811 EAR.

Food & agriculture

John Woodward [b. 1665, d. 1729] experiments with growing plants in rainwater with some dissolved soil. He shows

that plants use much more water than they retain, correctly concluding that plants release water to the atmosphere. In addition, he concludes that the experiment demonstrates that plants grow because of dissolved substances in water, which is partly true but not actually established by his experiment. *See also* 1648 BIO.

1700

Biology

Institutiones rei herbariae (“characteristics of things in a herb collection”) by botanist Joseph de Tournefort [b. Aix en Provence, France, June 5, 1656, d. Paris, December 28, 1708] is an illustrated work on plant life in the Mediterranean, published in three volumes. It is said to be the first work in which the distinction between species and genus is clearly made, earning Tournefort the title “father of the genetic concept.” *See also* 1693 BIO; 1735 BIO.

Earth science

Edmond Halley’s magnetic charts of the Atlantic and Pacific oceans show lines of equal magnetic variation. This is the second known map of magnetic variations from true north, 170 years after the first. *See also* 1530 EAR.

Guillaume Delisle [b. Paris, February 28, 1675, d. Paris, January 25, 1726] produces a map in which coordinates of locations are determined by astronomical observations.

Materials

In England men begin wearing suspenders to hold up

their trousers. *See also* 1580 MATR.

Medicine & health

De morbis artificum (“on occupational disease”) by Bernardino Ramazzini [b. Carpi (Italy), November 3, 1633, d. Padua, Italy, November 5, 1714] is the first systematic treatment of occupational disorders. Ramazzini concludes that more nuns than married women develop breast cancer, possibly for reasons related to pregnancy and lactation. *See also* 1775 ECOL.

Tools

The flintlock for igniting a charge in small arms is developed from a similar device, the snaphaunce lock, shortly before this date.

Christopher Polhem of Sweden improves the rolling mill, including a mill that can produce metal plates with profiles. *See also* 1550 TOOL; 1790 TOOL.



FLINTLOCK GUN The flintlock was one of the great technological advances of this period. The spring-loaded hammer contains a small piece of flint that produces a spark when released as the flint strikes a steel region; the spark ignites a small amount of powder in a shallow pan. Flames from the pan are channeled into the gun barrel to fire the weapon.

1701

Communication

Vincenzo Maria Coronelli [b. Venice (Italy), August 15, 1650, d. Venice, December 9, 1718] begins to publish his *Biblioteca universale sacro-profana* in Italian, the first of the great alphabetically arranged encyclopedias, but by 1706 he reaches only seven volumes (A to Caque) of the 45 volumes planned, and the project is abandoned. *See also* 1694 COMM; 1704 COMM.

Food & agriculture

Jethro Tull [b. Basildon, England, March 30, 1674, d. Hungerford, England, February 21, 1741] invents the machine drill for planting seeds in rows. This enables cultivation between rows. *See also* 1577 FOOD; 1731 FOOD.

Medicine & health

Greek physician Giacomo Pylarini, considered by some the first immunologist, inoculates three children with smallpox in Constantinople in the hope of preventing their developing more serious cases when they are older. *See also* 1713 MED.

Physics

Joseph Sauveur [b. La Fleche, France, March 24, 1653, d. Paris, July 9, 1716] introduces the term “acoustics” in a work on the relation of tones of the musical scale. *See also* 1636 COMM.

Tools

Charles Plumier publishes *L'art de tourner* (“the art of turning”), which gives the first detailed description of using a

lathe for turning iron. *See also* 1697 TOOL.

1702

Astronomy

Astronomiae physicae et geometriae elementa (“elements of astronomy, physics, and geometry”) by Scottish mathematician and astronomer David Gregory [b. Aberdeen, Scotland, June 3, 1659, d. Maidenhead, Berkshire, England, October 10, 1708] is the first astronomy textbook based on Newton’s new theory of gravitation. *See also* 1687 PHY.

Biology

Leeuwenhoek describes many protists in a letter to the Royal Society. *See also* 1696 BIO.

Chemistry

Wilhelm Homberg [b. Batavia, Indonesia, January 3, 1652, d. Paris, September 24, 1715] discovers boric acid. *See also* 1695 CHEM.

Communication

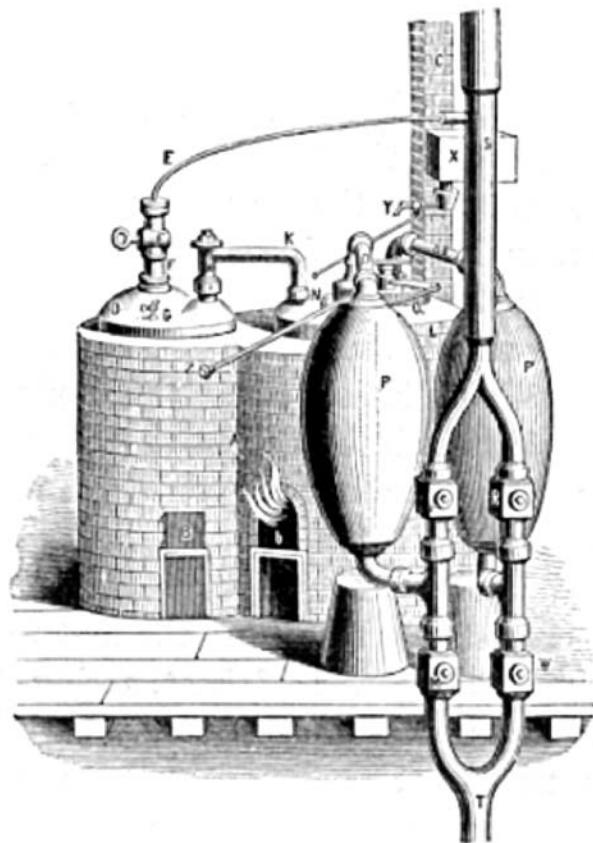
The English *Daily Courant* is thought to be the world’s first daily newspaper. *See also* 1605 COMM.

Energy

Thomas Savery’s *The Miner’s Friend* gives a description of his steam engine. *See also* 1698 ENER; 1707 ENER.

Physics

Physico-mechanical Experiments by Francis Hauksbee [b. Colchester, England, c. 1666, d. London, April 1713] describes how air at low pressure glows during an electrical discharge. *See also* 1703 ENER.



THOMAS SAVERY'S MINER'S FRIEND Savery's steam engine was similar to Papin's, but had no cylinder. The hot steam that filled the chamber was first used to push water up from the mine, then cold water was used to speed condensation. The partial vacuum produced lifted more water out of the mine.

I Tools

Guillaume Amontons invents a thermometer using air as the expandable fluid, but improves on Galileo's earlier design by using air pressure instead of volume. *See also* 1592 TOOL; 1709 TOOL.

1703

Communication

Newton is elected president of the Royal Society. *See also* 1660 COMM; 1704 COMM.

■ Construction

The Eddystone Light, undergoing repairs, is swept away in a storm, along with the repair ship and Henry Winstanley, the builder of the light. *See also* 1699 CONS; 1755 CONS.

■ Earth science

Jean de la Hautefeuille [b. Orléans, France, March 20, 1647, d. Orléans, October 18, 1724] designs the first Western seismograph; it is based on mercury. *See also* 132 CE EAR; 1900 EAR.

■ Energy

Francis Hauksbee produces a faint electric light by agitating mercury in a vacuum, which he demonstrates to the Royal Society. Over the next few years he continues to demonstrate various electrical experiments. *See also* 1650 ENER; 1709 ENER.

1704

★ Astronomy

Giacomo Maraldi [b. Perinaldo (Italy), August 21, 1665, d. Paris, December 1, 1729] discovers the variability of the star R Hydrae. *See also* 1687 AST.

Ole Römer constructs a private observatory on the outskirts of Copenhagen and builds the first telescope based on a meridian circle and the first altazimuth circle, which enables him to determine the position of objects before they cross the meridian. *See also* 1684 AST.

■ Biology

Charles Plumier's book *Nova plantarum americanarum genera* ("new genera of American plants") describes about 700 species in a hundred genera, using a system that is later adapted by Linnaeus. *See also* 1693 BIO; 1735 BIO.

□ Chemistry

The German color maker Heinrich Diesbach discovers the first artificial pigment, Prussian blue (now known as iron blue). Diesbach accidentally forms the blue pigment while trying to form a bright red. The secret of the pigment's manufacturing process is finally published in 1724. *See also* 1826 CHEM.

■ Communication

Newton revives the Royal Society, which because of lack of interest in natural science is almost defunct. *See also* 1697 COMM; 1731 COMM.

London clergyman John Harris [b. Shropshire, England, c. 1667, d. Norton Court, Kent, England, September 9, 1719] produces the first alphabetical encyclopedia in English. The *Lexicon Technicum, or an Universal English Dictionary of the Arts and Sciences* explains 8000 scientific terms in one volume; a second volume appears in 1710. *See also* 1701 COMM; 1728 COMM.

▼ Medicine & health

De aure humana tractatus ("anatomy and diseases of the ear") by Antonio Maria Valsalva [b. Imola (Italy), June 17, 1666, d. Bologna (Italy), February 2, 1723] provides the first detailed description of the physiology of the ear. *See also* 1660 MED; 1708 MED.

✿ Physics

Newton's *Optics* combines mathematics with experiment and accepts that light is particulate in nature, although Newton admits that these particles may also create vibrations in the ether. The book becomes a standard text in experimental physics for the rest of the century. It closes with a series of famous questions posed by Newton. *See also* 1678 PHY; 1729 PHY.

I Tools

Nicolas Fatio de Duillier [b. 1664, d. 1753] uses gems for bearings in clocks. *See also* 1680 TOOL; 1715 TOOL.

1705

◆ Archaeology

An Austrian cavalry officer who owns some land at Ercolano (Italy) has shafts dug in the successful search for Roman statues. *See also* 1736 ARCH.

★ Astronomy

The Royal Observatory of Berlin is founded. *See also* 1675 AST.

Philosophical Principles of Natural Religion by George Cheyne [b. Methlick, Scotland, 1671, d. Bath, England, April 13, 1743] argues for the existence of a Deity as a result of the observed phenomenon of attraction. *See also* 1710 MATH.

Edmond Halley is the first to recognize that comets are periodic. He correctly predicts in *Synopsis astronomiae cometicae* ("summary of comet astronomy") the return in 1758 of the comet that appeared in 1682, and which comes to be called Halley's comet. Officially it is called Comet Halley today. *See also* 1682 AST.

● Earth science

Richard Waller publishes posthumously Robert Hooke's lectures delivered at the Royal Society. One of them, "Lectures and Discourses on Earthquakes," explains how earthquakes might have changed the surface of the Earth substantially since its creation. *See also* 1760 EAR.

♥ Medicine & health

Raymond Vieussens [b. Vigan, France, c. 1635, d. Montpellier, France, August 16, 1715] gives the first accurate description

of the left ventricle of the heart, the valve of the large coronary vein, and the course of coronary blood vessels. *See also* 1669 MED; 1773 BIO.

❀ Physics

Francis Hauksbee experiments with a clock in a vacuum to prove sound needs air to travel. *See also* 1703 ENER; 1855 PHY.

1706

Σ Mathematics

Synopsis palmariorum matheseos, or A New Introduction to the Mathematics by William Jones [b. Anglesey, Wales, 1675, d. London, July 3, 1749] is the first known text to use the Greek letter π (pi) to represent the ratio of the circumference of a circle to its diameter. *See also* 1717 MATH.

♥ Medicine & health

Adversaria anatomica prima ("first anatomical notes") by Giovanni Battista Morgagni [b. Forlì (Italy), February 25, 1682, d. Padua (Italy), December 5, 1771] makes him known as an anatomist throughout Europe. *See also* 1761 MED.

❀ Physics

Francis Hauksbee reports to the Royal Society that a glass tube that attracts bits of brass leaf after rubbing no longer attracts the brass after contact is made. Instead, the glass tube begins to repel the brass. *See also* 1733 PHY.

1707

↗ Energy

Denis Papin modifies Thomas Savery's high-pressure steam

pump, including a safety valve and a way to prevent unwanted condensation of steam. *See also* 1702 ENER; 1712 ENER.

Σ Mathematics

Newton's *Arithmetica universalis* ("universal arithmetic") includes a precise formulation of Descartes' "Rule of Signs," which determines the greatest possible number of positive solutions and the number of negative solutions to an equation based on how many changes of sign (plus and minus) occur in the equation.

♥ Medicine & health

De subitaneis mortibus ("on sudden death") by Giovanni Maria Lancisi [b. Rome, October 26, 1654, d. Rome, January 21, 1720] founds cardiac pathology. *See also* 1705 MED; 1795 MED.

Georg Stahl's *Theoria medica vera* ("the true story of medicine") expounds Stahl's animalistic theory associating the soul with the physiologic processes.

The Physician's Pulse Watch by John Floyer [b. Hintess, England, 1649, d. Litchfield, England, February 1, 1734] introduces pulse rate counting in medical practice and puts forth a special watch for it. *See also* 1603 MED.

I Tools

Admiral Sir Cloudesley Shovel [b. 1650, d. off Scilly Islands, October 22, 1707] allows the British fleet to get lost in heavily overcast weather. Thinking they are off the coast of Brittany, the ships run aground on the Scilly Islands off the southwest coast of England. Four ships and 2000 men, including the admiral, are killed. The dis-

aster leads Britain to offer a prize for a way to tell longitude at sea. *See also* 1714 TRAN.

1708

❖ Materials

Johann F. Böttger [b. Schleiz (Germany), February 4, 1682, d. 1719], a chemist working for Augustus the Strong of Saxony, and Count Ehrenfried von Tschirnhaus, rediscover how to make true hard-paste porcelain from kaolin, a process that had been kept secret in the Orient. *See also* 1616 MATR.

♥ Medicine & health

Institutiones medicae by Hermann Boerhaave [b. Voorhout (Netherlands), December 31, 1668, d. Leiden, Holland, September 23, 1738] explains his theory of inflammation. The book combines mechanical views of physiology with the idea that physiological processes are chemical fermentations. *See also* 1704 MED.

I Tools

Christopher Polhem develops machine tools for the production of cogwheels. *See also* 1697 TOOL.

1709

↳ Communication

The Copyright Act introduced in England protects an author for 21 years, guaranteeing an income proportional to the sales of a book. *See also* 1623 COMM.

■ Construction

The second Eddystone Light, built by John Rudyerd starting in 1706 after the first was swept away in a storm, is a 28-

m (92-ft) circular wooden tower. *See also* 1703 CONS; 1755 CONS.

❖ Energy

Newton builds an electric generator consisting of a rotating glass sphere. Francis Hauksbee improves the design by using a metal chain to capture the electricity generated by friction. *See also* 1660 ENER.

Francis Hauksbee produces a faint electric light by rotating an evacuated glass globe and rubbing it with his hand, described in his *Physico-Mechanical Experiments* of 1709 and in public lectures in 1712. *See also* 1703 ENER; 1729 PHY.

❖ Materials

Around this time the eldest of three generations of Abraham Darbys [b. near Dudley, Worcestershire, England, 1678, d. Madley Court, Worcestershire, England, March 8, 1717] sets up an ironworks at Coalbrookdale, Shropshire, England, where he develops improved methods of making iron castings and develops ways of making coke free of impurities by heating coal in airtight containers. *See also* 1665 MATR; 1750 MATR.

♥ Medicine & health

New Theory of Vision by George Berkeley [b. County Kilkenny, Ireland, March, 1685, d. Oxford, England, January 14, 1753] is the most significant contribution to psychology in the 18th century.

I Tools

Gabriel Daniel Fahrenheit [b. Danzig (Gdańsk, Poland), May 24, 1686, d. The Hague (Netherlands), September 16, 1736] constructs an alcohol

thermometer. *See also* 1654 TOOL; 1730 TOOL.

1710

❖ Communication

A private scientific society is founded at Uppsala, Sweden, by Erik Benzelius [b. 1675, d. 1743], Emanuel Swedenborg [b. Stockholm, Sweden, January 29, 1688, d. London, March 29, 1772], and Christopher Polhem. In 1728 it becomes the Kungliga Vetenskaps Societeten. *See also* 1666 COMM; 1724 COMM.

Jacob Christoph Le Blon [b. Frankfort (Germany), May 1667, d. Paris, May 15, 1741] invents three-color printing. *See also* 1485 COMM; 1719 COMM.

Σ Mathematics

A short paper “An Argument for Divine Providence, Taken from the Constant Regularity Observ’d in the Birth of Both Sexes” by John Arbuthnot [b. Inverbervie, Scotland, April 1667, d. London, February 27, 1735] is one of the ancestors of modern statistical reasoning. *See also* 1705 AST.

1711

❖ Biology

Luigi Marsigli [b. Bologna (Italy), July 10, 1658, d. Bologna, November 1, 1730] shows the animal nature of corals, formerly held to be plants. *See also* 1842 EAR.

1712

★ Astronomy

John Flamsteed’s first volume of his star catalog, *Historia coelestis Britannica*, published

without the author’s permission, catalogs the position of nearly 3000 stars and replaces Kepler’s catalog. An official, three-volume edition appears posthumously in 1725. *See also* 1679 AST; 1725 AST.

❖ Energy

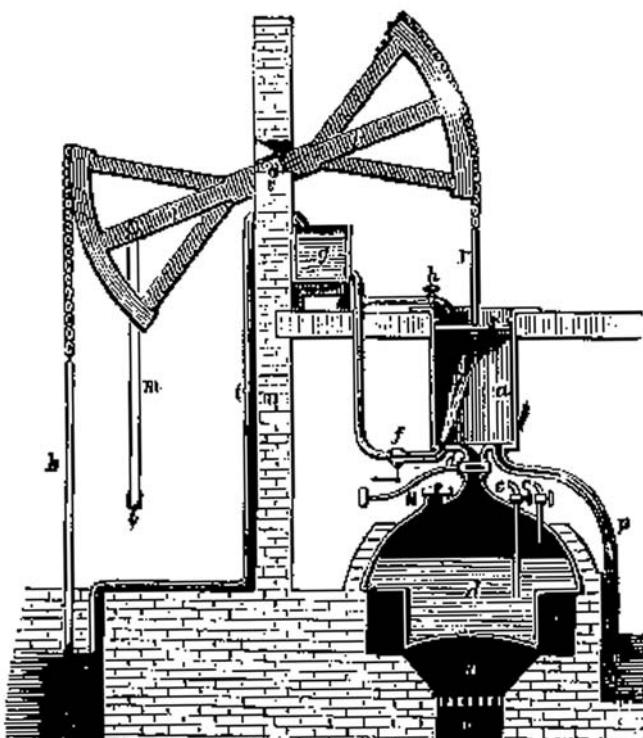
Thomas Newcomen [b. Dartmouth, England, February 24, 1663, d. London, August 5, 1729], in collaboration with Thomas Savery, erects near Dudley Castle the first practical steam engine to use a piston and cylinder, bringing the engine out of the laboratory and into the workplace for the first time. It drives a pump in a mine and produces about

5.5 hp. *See also* 1707 ENER; 1723 ENER.

Σ Mathematics

Giovanni Ceva’s *De re numeraria* (“concerning money matters”) is the first clear application of mathematics to economics.

Brook Taylor [b. Edmonton, Middlesex, England, August 19, 1685, d. London, December 29, 1731], in a letter, describes the Taylor expansion for the first time. This is a method of expressing a polynomial as an infinite series based on the successive derivatives of the function. *See also* 1715 MATH.



THE NEWCOMEN ENGINE Newcomen reintroduced the cylinder to the steam engine, but separated it from the steam chamber, which meant that the cylinder did not alternate between hot and cold. Condensation of the steam in the chamber allowed the atmosphere to push the cylinder down. A lever attached to the cylinder then moved up to power the pump. The action was reciprocating—that is, up and down.

1713

Biology

In *Physico-theology, or a Demonstration of the Being and Attributes of God from His Works of Creation*, William Derham [b. Stoughton, England, November 26, 1657, d. Upminster, England, April 5, 1735] tries to show that this is the best of all possible worlds. See also 1705 AST.

Materials

René Antoine Ferchault de Réaumur [b. La Rochelle, France, February 28, 1683, d. France, October 18, 1757] presents to the Academy of Sciences in Paris a material entirely woven from glass fiber that probably was produced by Carlo Riva of Venice. See also 1679 MATR.

Mathematics

Nicholas (Nicolaus) Bernoulli [b. St. Petersburg, Russia, 1695, d. St. Petersburg, July 31, 1726] poses the probability problem known as the Petersburg paradox in a letter to Pierre Rémond de Montmort [b. Paris, October 27, 1678, d. Paris, October 7, 1719]. It involves the mathematical expectation of a simple coin-tossing game. Mathematical reasoning gives a result that is clearly wrong according to practical experience.

Ars conjectandi ("the conjectural arts"), a posthumously published treatise on probability by Jacques (Jakob) Bernoulli, contains the theorem named after him, a version of the law of large numbers. The theorem is the first application of calculus to probability theory. The book contains the laws of combi-

natics, also known as permutations and combinations, as well as the formulation of what are today called Bernoulli numbers, the coefficients of a particular infinite series important in describing trigonometric and other functions. See also 1689 MATH; 1718 MATH.

Medicine & health

Greek physician Emanuel Timoni describes to the British Royal Society the Turkish practice of inoculating young children with smallpox to prevent more serious cases of the disease when they get older. See also 1701 MED; 1717 MED.

Surgeon William Cheselden [b. Somerby, England, October 19, 1688, d. Bath, England, April 10, 1752] publishes *Anatomy of the Human Body*. Cheselden became famous as a surgeon because of his speed and skill; as a result of both, some 90 percent of his patients survived surgery, an amazing record for the early 18th century.

Physics

The second revised edition of Newton's *Principia* is published with an introduction by Roger Cotes [b. Burbage, England, July 10, 1682, d. Cambridge, England, June 5, 1716] and containing the famous *General Scholium*. Cotes spent four years editing the second edition, correcting many minor mathematical errors. See also 1687 PHY; 1729 PHY.

1714

Communication

Henry Mill, a London engineer, patents the first known

typewriter. Little is known today about how the device worked, if it did. The patent claims his device can impress letters "so neat and exact as not to be distinguished from print." See also 1867 COMM.

Mathematics

Roger Cotes gives one of the first forms of the theorem, usually attributed to Euler, that the natural logarithm of the sum of the cosine of an angle and i times the sine is equal to i times the angle, or $\ln(\cos \theta + i \sin \theta) = i\theta$, where $i = \sqrt{-1}$.

Medicine & health

Dominique Anel [b. Toulouse, France, c. 1679, d. 1730] invents the fine-point syringe, still known by his name, for use in treating *fistula lachrymalis*. See also 1721 MED.

Tools

Gabriel Fahrenheit builds a mercury thermometer with a scale that will be named after him. The thermometer uses zero as the coldest temperature he can produce. See also 1709 TOOL; 1730 TOOL.

Transportation

The British Parliament passes a bill setting up a prize of £20,000 for the first person to develop a sufficiently accurate way to find the longitude at sea. See also 1616 EAR; 1716 TRAN.

1715

Food & agriculture

American Thomas Masters files a patent in England for the invention by his wife Sybilla of a machine for preparing kernels from corn

on the cob using a combination of wooden cogwheels, mortars, and drying trays, powered either by a horse or a water wheel.

Mathematics

Brook Taylor develops in *Methodus incrementorum directa et inversa* ("direct and inverse methods for making small changes") the calculus of finite differences and integration by parts. It also contains the series named after him. He also publishes *Principles of Linear Perspective*. Both books will be re-issued in 1717 and 1719. See also 1719 MATH; 1797 MATH.

Tools

John Harrison [b. Foulby, England, March 24, 1693, d. London, March 24, 1776] constructs an eight-day clock (it needs to be wound only once a week). See also 1704 TOOL.

George Graham [b. Cumberland, England, c. 1674, d. 1751] invents the deadbeat escapement for clocks, a device that gives a tiny shove to the pendulum near the center of the swing and drags slightly on it as it goes to the extremities, improving the accuracy of the clock to a few seconds per day. See also 1670 TOOL; 1720 TOOL.

1716

Construction

The first North American lighthouse north of Mexico is the Boston Light on Little Brewster Island in Boston Harbor. At sunset on September 14 the light is lit for the first time. It lasts until the American Revolution, when it is destroyed first by the

Temperature

Some of the measurements we take for granted were not known in the ancient world. Among them is temperature. Certainly, ancient people knew that it was cold sometimes and hot sometimes, but no one had a way of putting a number to it. It was Galileo who made the first steps toward a quantitative means of measuring temperature. He noted that gases expand when heated. Using this principle, he developed a thermoscope, an inaccurate gas thermometer. Although Galileo did not know it, the gas he used — air — changed in volume according to outside air pressure as well as heating.

A really good thermometer was not made until 1714, when Gabriel Fahrenheit made the first mercury thermometer. Instead of air Fahrenheit used changes in the expansion of mercury to measure temperature. He set 0° as the lowest temperature he could reach by freezing salted water, hoping to avoid negative temperatures.

Anders Celsius did not create a new type of thermometer, but he did create the scale that is most commonly used around the world today. In one of the great mistakes of science, Celsius first set his scale with 0° as the temperature of boiling water and 100° as the temperature of freezing water. Wiser heads prevailed,

however, and the scale was reversed. Until 1948 the scale Celsius devised was known in the United States as *centigrade*, but that year scientists agreed to rename it after its inventor. Gradually the world has gotten used to the idea that 37°C means 37 degrees Celsius, not 37 degrees centigrade.

More accurate thermometers have been developed over the years. Instead of using the simple expansion of materials upon heating, other thermometers use differences in the coefficient of expansion of two metals, the amount of energy emitted at different temperatures by certain substances, or the changes in electrical resistance at different temperatures.

Fahrenheit's idea of a temperature scale with no negative numbers was achieved with the introduction of the Kelvin scale (sometimes called the absolute scale). Lord Kelvin observed in 1848 that Charles's law, which states that gases lose 1/273 of their volume for every degree below 0°C, implies that at -273° the volume becomes zero. He proposed that -273° must be the lowest temperature obtainable, since nothing has a negative volume. This concept has since been verified. Today absolute zero is set more accurately at -273.15°C (-459.7°F). On the Kelvin scale, then, the freezing point of water is 273.15 K (no degree sign is used) and the boiling point is 373.15 K.

colonists and then, more completely, by the British as they evacuate Boston in 1776. *See also* 1709 CONS.

Σ Mathematics

Leibniz sends Newton a difficult problem (finding the orthogonal trajectories of a family of hyperbolas having the same vertex) to test his skills. Newton receives the problem about 5:00 p.m. on returning from a long day at the mint, where he is master, and solves it before going to bed.

I Tools

Philippe De la Hire invents the double-acting water pump, which produces a continuous stream of water. *See also* 1676 TOOL.

✈ Transportation

Edmond Halley develops a diving bell with a system for

refreshing the air and demonstrates its use. *See also* 1620 TRAN.

The French government offers prizes for finding the longitude at sea with accuracy. *See also* 1714 TRAN.

1717

Σ Mathematics

Abraham Sharp [b. Bradford, England, 1651, d. Bradford, 1742] finds the value of π to 72 places. *See also* 1706 MATH; 1768 MATH.

♥ Medicine & health

Lady Mary Wortley Montagu [b. London, 1689, d. London, April 29 or August 21, 1762] brings back to England the Turkish practice of inoculation and has her own two children vaccinated against smallpox. *See also* 1701 MED; 1721 MED.

Giovanni Lancisi suggests in *De noxiis paludum effluviis* ("on the noxious effluvia of marshes") that malaria can be transmitted by a mosquito. *See also* 1892 MED.

1718

★ Astronomy

Edmond Halley discovers proper motion of stars — that is, apparent motion with respect to other stars — by comparing star positions he has determined with those given by Hipparchus and Ptolemy. *See also* 1773 AST.

▷ Chemistry

Etienne François Geoffroy [b. 1672, d. Paris, January 6, 1731] presents *Table des différents rapports en chimie* ("table of different chemical affinities"), the first table of affinities (attractions of sub-

stances to each other) to the French Academy. It shows how 16 substances, some elements and some compounds, combine or react. *See also* 1773 CHEM.

⊕ Earth science

Jacques Cassini [b. Paris, February 8, 1677, d. Paris, April 18, 1756] publishes his and his father's (Giovanni Cassini's) measurements supporting Descartes' prediction (later proven faulty) that Earth is elongated at the poles. *See also* 1736 EAR.

Σ Mathematics

Jacques Bernoulli's *Mémoires de l'académie des sciences* ("notes of the academy of sciences"), published posthumously, contains the basic concepts of the calculus of variations, the mathematical treatment of functions that are the maximum or mini-

mum function for some specific conditions. *See also* 1697 MATH; 1744 MATH.

Doctrine of Chances by Abraham De Moivre [b. Vitry-le-François, France, May 26, 1667, d. London, November 27, 1754] is De Moivre's first book on probability. *See also* 1613 MATH; 1725 MATH.

♥ Medicine & health

German physician Friedrich Hoffmann [b. Halle (Germany), February 19, 1660, d. Halle, November 12, 1742] begins publication of the nine volumes of his *Medicina rationalis systematica*, in which he introduces the concept of muscle tone as a measure of health.

✈ Transportation

A canal joins the Baltic and Caspian seas in Russia via the Volga River.

1719

☛ Communication

Jacob Le Blon patents a color-printing system based on the reconstruction of colors from primary colors by superimposing images obtained with plates inked in blue, yellow, red, and black. *See also* 1710 COMM.

Σ Mathematics

The third edition of *Principles of Linear Perspective* by English mathematician Brook Taylor gives the first general statement of the principle of the vanishing point. *See also* 1715 MATH.

1720

★ Astronomy

Edmond Halley succeeds

Flamsteed as Astronomer Royal and starts on an 18-year study of the Moon. He discovers secular (long-term) acceleration, the gradual speeding up of the Moon's motion in orbit by about 28 cm (11 in.) per century, caused by tidal friction. Secular acceleration also slows Earth's rotation, increasing the length of the day by about 0.001 second per century.

■ Construction

The Corps des Ingénieurs des Ponts et Chaussées ("group of engineers for bridges and roads") is formed in France. It is the first such group for civilian engineering projects.

■ Food & agriculture

Joseph Foljambe takes out the first English patent on a mold-board plow sheathed in iron, although iron-sheathed plows had been used in England even before Roman times. *See also* 1819 FOOD.

Σ Mathematics

Daniel Bernoulli solves one version of the differential equation, $y' = p(x)y^2 + q(x)y + r(x)$, of Jacopo Francesco Riccati [b. Venice (Italy), May 28, 1676, d. Treviso (Italy), April 15, 1754], although the general solution will not be found until 1760, when Euler solves it. *See also* 1724 MATH.

Geometrica organica by Colin Maclaurin [b. Kilmodan, Scotland, February, 1698, d. Edinburgh, Scotland, June 14, 1746] discusses the properties of curves formed by equations of the second, third, fourth, and general degree (the degree is the sum of the exponents of the term for which that sum is greatest).

A brief essay on "negativo-affirmative arithmetic" by English mathematician John Colson [b. c. 1600, d. 1760], written about this time, shows how to calculate with numbers expressed in any base. *See also* 1820 MATH.

■ Tools

George Graham develops the cylinder escapement, a version of his deadbeat escapement that can be used with clocks based on balance wheels instead of pendulums. *See also* 1715 TOOL; 1725 tool

1721

♥ Medicine & health

Jean Palfyn [b. Kortrijk, Flanders (Belgium), 1650, d. Ghent, Flanders (Belgium), April 21, 1730] introduces the use of obstetric forceps for facilitating birth. *See also* 1714 MED.

Zabdiel Boylston [b. Brook-

line, Massachusetts, March 9, 1679, d. Brookline, March 1, 1766] introduces inoculation against smallpox into America during the Boston epidemic. *See also* 1717 MED.

❀ Physics

Mathematical Elements of Natural Philosophy Confirmed by Experiments, or an Introduction to Sir Isaac Newton's Philosophy by Willem Jacob van 'sGravesande [b. Hertogenbosch, Holland (Netherlands), September 26, 1688, d. Leiden, Holland (Netherlands), February 28, 1742] provides strong Continental support for Newton's physics. *See also* 1687 PHY.

■ Tools

George Graham develops the mercury compensating pendulum for clocks. A jar of mercury is used as a pendulum bob so that as the mercury expands with temperature it will just compensate for the expansion of the brass rod of the pendulum. *See also* 1656 TOOL; 1726 TOOL.

1722

⊕ Earth science

Dutch admiral Jakob Roggeveen [b. 1659, d. 1729] discovers Easter Island. *See also* 1728 EAR.



Daniel Bernoulli

[b. Groningen, Holland, February 8, 1700, d. Basel, Switzerland, March 17, 1782]

Daniel, son of Jean (Johann) Bernoulli, contributed to oceanography and astronomy as well as mathematics but is best known for his work in physics. He established Bernoulli's principle: A fluid produces less pressure as its velocity increases, an effect that provides much of the lift for airplanes. He also was the first to use the idea that a gas is made from tiny particles, thus deriving the gas laws, which had previously been discovered experimentally.

☛ Energy

The first steam engine on the European continent is erected at Königsberg (Kaliningrad, Russia), near Schemnitz. *See also* 1712 ENER.

❖ Materials

René de Réaumur's *L'arte de convertir le fer forgé en acier* ("the art of converting iron into steel") is the first technical treatise on iron. He also discovers the role of carbon in the hardness of steel. *See also* 1674 MATR; 1734 MATR.

Σ Mathematics

Roger Cotes's *Harmonia mensurarum* ("harmony of measures"), published posthumously, is among the earliest works to recognize that the trigonometric functions are periodic.

1723

❖ Chemistry

Georg Stahl's *Fundamenta chymiae dogmaticae et experimentalis* ("foundations of theoretical and experimental chemistry") popularizes the views on combustion of Johann Becher, notably the phlogiston theory. *See also* 1697 CHEM; 1783 CHEM.

■ Construction

Nicholas Bion [b. France, 1653, d. Paris, 1733] describes the surveying instruments of the day, most of which are still in use today.

☛ Energy

Jacob Leupold [b. Planitz (Germany), July 25, 1674, d. Leipzig (Germany), January 12, 1727] publishes *Theatrum machinarum generale* (nine volumes, 1723–39), the first systematic treatment of

mechanical engineering. The work includes the design of a noncondensing, high-pressure steam engine comparable to those built at the beginning of the 19th century. *See also* 1712 ENER; 1725 ENER.

♥ Medicine & health

Drinkers from North Carolina complain that rum from Massachusetts causes stomach problems and partial paralysis. After Boston physicians attribute the problem to lead parts used in the stills that produce the rum, the Massachusetts legislature outlaws that use of lead. *See also* 1767 MED.

❀ Physics

Swiss physician Maurice A. Capeller's *Prodromus crystallographiae* ("introduction to crystallography") is the earliest treatise on crystallography.

Brook Taylor mixes different proportions of hot and cold water and measures the resulting temperatures, thus contributing to the discovery of the so-called law of mixtures: The temperature of a mixture of substances is the weighted mean of the temperatures of the substances making up the mixture.

1724

⌚ Communication

Peter the Great founds the Academy of Sciences at St. Petersburg, Russia. It attracts many of the leading mathematicians of Europe, including Nicholas and Daniel Bernoulli and Leonhard Euler. *See also* 1660 COMM; 1731 COMM.

♫ Food & agriculture

Paul Dudley discovers the possibility of cross fertilizing corn.

Σ Mathematics

Jacopo Riccati publishes his analysis of what has come to be called the Riccati differential equation: $dy/dx = A(x) + B(x)y + C(x)y^2$. *See also* 1720 MATH.

❀ Physics

Hermann Boerhaave's *Elementae chemiae* ("elements of chemistry") argues — incorrectly — that heat is a fluid, a theory that came to be called the caloric theory after the name of the supposed fluid. *See also* 1798 PHY.

Gabriel Fahrenheit describes supercooled water, water that is liquid below its freezing point.

1725

★ Astronomy

John Flamsteed's three-volume *Historia coelestis* ("celestial history"), published posthumously, catalogs 2884 stars. *See also* 1712 AST.

⌚ Communication

Scottish goldsmith William Ged [b. 1690, d. 1749] improves stereotype printing, a technique developed during the 15th century. Instead of printing from the type directly, pages are printed from a plate made of lead, which is obtained by pouring lead in a mold made from papier mâché of the composed type. The plates can then be reused for reprints. *See also* 1793 COMM.

❀ Earth science

Luigi Marsigli's *Histoire physique de la mer* ("physical story of the sea") is the first treatise on oceanography. *See also* 1855 EAR.

Homo diluvii testis ("human witness to the flood") by Johann Jakob Scheuchzer [b. Zürich, Switzerland, August 2, 1672, d. Zürich, June 23, 1733] is an important work on fossils. But Scheuchzer misinterprets fossil remains of a giant salamander, saying they are remains of a human drowned in Noah's Flood. *See also* 1699 EAR.

☛ Energy

A steam engine is operating at a coal mine at Jemeppe-sur-Meuse, near Liège (Belgium). It is one of the earliest steam engines erected on the Continent. *See also* 1722 ENER; 1726 ENER.

❖ Materials

Hammered, wrought-iron plate becomes available commercially.

Σ Mathematics

Abraham De Moivre's *Annuities on Lives* is the first important mathematical book on the subject of annuities. *See also* 1718 MATH; 1733 MATH.

I Tools

George Graham develops the horizontal escapement, incorporating a rotating cylinder that replaces the function of the anchor. *See also* 1720 TOOL; 1726 TOOL.

Basile Bouchon develops a semiautomatic weaving loom in which the index fingers (which lift and lower the warp threads) are controlled by an endless paper tape. Feeding the paper tape is still manual. The loom will be fully automatic in later designs by Vaucanson and Jacquard. *See also* 1775 TOOL.

1726

❖ Energy

John May and John Meeres build a steam engine for providing Paris with water from the Seine at Passy near Paris. *See also* 1725 ENER; 1732 ENER.

♥ Medicine & health

Stephen Hale [b. Bekesbourne, England, September 17, 1677, d. Teddington, England, January 4, 1761] makes the first measurement of blood pressure of the horse.

I Tools

John Harrison constructs a gridiron compensating pendulum clock as a way to counteract the expansion in the length of a pendulum caused by temperature. *See also* 1721 TOOL; 1896 MATR.

1727

❖ Biology

Stephen Hales lays the foundations of plant physiology with *Vegetable Staticks or Statistical Essays on Nutrition of Plants and Plant Physiology*, discussing the ascent of liquids in plants. *See also* 1733 BIO.

❖ Chemistry

Stephen Hales describes in *Vegetable Staticks* the methods he has invented for collecting gases (which he calls “air”) and separating them from their generating sources. This is the forerunner of the methods used by later 18th-century chemists.

Johann Heinrich Schulze [b. 1684, d. 1744] discovers that silver salts turn black as a

result of exposure to light. *See also* 1565 CHEM; 1810 COMM.

❖ Energy

The first known attempt to brighten a lighthouse light is a tin reflector at the Cordouan Light off the coast of France. *See also* 1611 CONS; 1763 TOOL.

Σ Mathematics

Bernard de Fontenelle's *Éléments de la géometrie de l'infini* (“elements of the geometry of infinity”) gives his theory of the calculus of infinity. *See also* 1676 MATH.

Leonhard Euler [b. Basel, Switzerland, April 15, 1707, d. St. Petersburg, Russia, September 18, 1783] in correspondence introduces *e* as the symbol for the base of the natural logarithms. It will appear in print for the first time in Euler's *Mechanica, sive motus scientia analytice exposita* in 1736.

1728

★ Astronomy

James Bradley [b. Sherborne, England, March 1693, d. Chalford, England, July 13, 1762] explains the observed periodic shifts of stars by the aberration of light. Stars shift their apparent position depending on whether Earth is moving toward or away from them (called the aberration of light), demonstrating that Earth indeed revolves about the Sun. *See also* 1543 AST.

In *Hesperi et phosphori nova phaenomena sive observationes circa planetam Veneris* Francesco Bianchini [b. Verona (Italy), December 13, 1662, d. Rome, March 2, 1729] estimates the rotation period

of Venus as 24 and a third days (far from its correct value of 243 days in a direction opposite that of the other planets).

❖ Communication

Ephraim Chambers [b. Kendal, England, 1680, d. London, May 15, 1740] publishes one of the most influential and popular works of the time, the *Cyclopedie, or an Universal Dictionary of Art and Sciences* in two volumes. In translation it becomes the first complete Italian encyclopedia as well as the progenitor of the great French encyclopedia of Diderot. *See also* 1704 COMM; 1743 COMM.

⊕ Earth science

Vitus Jonassen Bering [b. Horsens, Denmark, summer, 1681, d. Bering Island, east of Kamchatka, December 19, 1741] discovers the Bering Strait. *See also* 1722 EAR.

♥ Medicine & health

Le chirurgien dentiste, ou traité des dents (“the surgeon dentist, or treatise of the teeth”) by Pierre Fauchard [b. 1677, d. Paris, March 21, 1761] puts dental treatment on a more scientific plane and describes how to fill a tooth infected with dental caries using tin, lead, or gold. The post crown, an artificial top portion of a tooth mounted on a post inserted into the root canal, is introduced. *See also* 1890 MED.

Giovanni Lancisi's posthumously published *De motu cordis et aneurysmatibus* discusses heart dilatation. *See also* 1717 MED.

I Tools

Jacques de Falcon builds a semiautomatic weaving loom

in which the index fingers (which lift and lower the warp threads) are controlled by perforated cards. The cards must be fed into the machine manually. *See also* 1725 TOOL; 1733 TOOL.

1729

❖ Biology

Louis Bourget's *Lettres philosophiques sur la formation des sels et de cristaux et sur la génération et la mécanique organique* (“philosophical letters on the formation of salts and crystals and on generation and organic mechanisms”) makes the distinction between organic and inorganic growth.

■ Construction

Bernard Forest de Bélidor [b. Catalonia, Spain, c. 1693, d. Paris, 1761] publishes *La science des ingénieurs* (“knowledge or skill of engineers”), a handbook in mechanics for civil engineers dealing with forces in beams, pressure of soil, and construction of retaining walls. Because of its general usefulness, it is repeatedly reissued over the next hundred years. *See also* 1737 CONS.

Σ Mathematics

Isaac Greenwood's *Arithmetic Vulgar and Decimal* is the first mathematics textbook in America. *See also* 1733 MATH.

❖ Physics

Essai d'optique sur la gradation de la lumière (“essay on optics concerning gradation of light”) by Pierre Bouger [b. Le Croisic, France, February 16, 1698, d. Paris, August 15, 1758] reports on some of the earliest measurements in pho-

tometry (measurement of the luminosity of light). *See also* 1704 PHY.

Stephen Gray [b. Canterbury, England, 1666, d. London, February 25, 1736] discovers that electricity can be transmitted from one object to another and over distances through conductors and that static electric charges are on the surfaces of objects, not in the interiors. *See also* 1709 ENER.

Physicae experimentales et geometrae dissertationes (“physics experiments and dissertations on geometry”) by Pieter van Musschenbroeck [b. Leiden, Holland, March 14, 1692, d. Leiden, September 19, 1761] is one of the first books where the term *physics* is used for “natural philosophy.”

Andrew Motte publishes an English translation of Newton’s *Principia*. *See also* 1713 PHY.

1730

Chemistry

Georg Brandt [b. Riddarhyttan, Sweden, July 21, 1694, d. Stockholm, Sweden, April 29, 1768] discovers cobalt.

Medicine & health

George Martine performs the first tracheotomy for treatment of diphtheria.

Tools

René de Réaumur constructs an alcohol thermometer with a graduated scale from 0 to indicate freezing to 80 to indicate boiling. *See also* 1714 TOOL; 1742 TOOL.

Henri Pitot [b. Aramon, France, 1695, d. Aramon, 1771] invents a device for measuring the flow of fluids

that comes to be called the Pitot tube. First used to measure the flow of water in rivers and canals, it is today used on airplane wings to measure air flow as well as for hydraulic purposes.

1731

Astronomy

John Bevis [b. Old Sarum, England, November 10, 1695, d. Greenwich, England, November 6, 1771] at Greenwich Observatory observes the Crab Nebula.

Biology

Volume I of *The Natural History of Carolina, Florida, and the Bahama Islands* by Mark Catesby [b. Essex, England, April 3, 1682, d. 1749] appears. It is an account of the flora and fauna of the New World, complete with plates of Catesby’s watercolors and descriptions in both English and French. Volume II will appear in 1743 and an appendix in 1748. *See also* 1542 FOOD.

Communication

The Copley Medal is instituted by the Royal Society, London, following a 1709 bequest from Sir Godfrey Copley. It is awarded “to the living author of such philosophical research . . . That may appear to the council to be deserving of such honor.” *See also* 1660 COMM.

The Royal Dublin Society is founded in Ireland. *See also* 1724 COMM.

Food & agriculture

Jethro Tull’s *Horse-hoeing Husbandry* advocates the use of manure, pulverization of

the soil, growing crops in rows, and hoeing to remove weeds. *See also* 1701 FOOD.

Materials

Charles Marie de la Condamine [b. Paris, January 28, 1701, d. Paris, January 28, 1774] rediscovers rubber on the Amazon River (it was known from the time of Columbus’s second voyage). Jacques de Vaucanson [b. Grenoble, France, February 24, 1709, d. Paris, 1782] will use the material a few years later to make flexible hoses. *See also* 1493 MATR; 1735 MATR.

Physics

Stephen Gray demonstrates that anything can be charged with static electricity if it is isolated by nonconducting materials. His demonstration includes a live boy suspended from the ceiling with silk threads and electrified by exposure to a rubbed glass tube. *See also* 1729 PHY; 1734 PHY.

Tools

Independently, Englishman John Hadley and American Thomas Godfrey [b. Philadelphia, 1704, d. Bristol Township, Pennsylvania, December 1749] invent the sextant, an instrument for finding the altitude of the Sun that is based on the equality of the angle of incidence and the angle of reflection. It is so named because it uses a scale on a sixth part of a circle, although the Hadley version is actually an octant (based on an eighth of a circle). *See also* 1490 TOOL; 1757 TOOL.

The invention of the pyrometer by Pieter van Musschenbroeck is reported in the Latin edition of *Saggi di naturali*

esperienze fatte nell’ Accademia del Cimento (“essay on experiments with nature made by the Accademia del Cimento”). *See also* 1657 COMM.

1732

Earth science

Benjamin Franklin publishes the first issue of *Poor Richard’s Almanack*, which predicts weather and gives astronomical phenomena for 1733 as well as providing many pithy sayings that will become popular proverbs. *See also* 1680 AST; 1744 ENER.

Discours sur la figure des astres (“discourse on the shape of the heavenly bodies”) by Pierre Louis Moreau de Maupertuis [b. St. Malo, France, September 28, 1698, d. Basel, Switzerland, July 27, 1759] predicts the shape of Earth using Newtonian mechanics. *See also* 1718 EAR; 1736 EAR.



Benjamin Franklin

[b. Boston Massachusetts, January 17, 1706, d. Philadelphia Pennsylvania, April 17, 1790]

Franklin, best known as a statesman and author, was also a first-class scientist and inventor. He made major contributions to the theory of electricity, including the first recognition of conservation of charge, a theory of static electricity, and proof that lightning is an electrical phenomenon. He also recognized the importance of ocean currents and had the Gulf Stream mapped for the first time.

☛ Energy

Steam engines are used for rotary motion by pumping water into a raised tank that releases a stream of water to power a water wheel. *See also* 1726 ENER.

1733

★ Astronomy

Chester Moor Hall [b. Leigh, England, December 9, 1703, d. Sutton, England, March 17, 1771] discovers the way to correct the chromatic aberration of light caused by different wavelengths traveling through a lens. He constructs a second lens from a different form of glass, one that has exactly the opposite defects, which resolves the problem. The chromatic aberration in one kind of glass is compensated for by the other kind of glass.

☛ Biology

Stephen Hales's *Statistical Essays, Containing Haemostatics, etc.* reports his investigations on blood flow and pressure in animals and the hydrostatics of sap in plants. *See also* 1705 MED.

☛ Earth science

Anders Celsius [b. Uppsala, Sweden, November 27, 1701, d. Uppsala, April 25, 1744] publishes a compilation of his observations of the aurora borealis.

The Russian Great Nordic Expedition (1733–43), led by Vitus Bering, starts. Involving some 10,000 persons, it is often termed the greatest expedition ever. The main aim is to seek a sea passage from the Pacific to the Atlantic, in

which the expedition fails, but natural history and mapping are accomplished. *See also* 1728 EAR; 1741 EAR.

Σ Mathematics

Abraham De Moivre publishes the discovery of the normal curve of errors, or the normal distribution curve. *See also* 1718 MATH.

Euclid ab omni naevo vindicatus ("Euclid freed of every flaw") by Girolamo Saccheri [b. San Remo (Italy), September 5, 1667, d. Milan (Italy), October 25, 1733] is an attempt to prove Euclid's Parallel Postulate that instead lays the groundwork for non-Euclidean geometry. *See also* 1663 MATH; 1766 MATH.

Yale is the first American college to offer geometry, using Euclid's *Elements* as a textbook. *See also* 1729 MATH.

♥ Medicine & health

Experiments on blood pressure reported in *Haemostatics* by Stephen Hales relate pressure to various bodily conditions. Hales determines the velocity of blood flow and the capacity of the different blood vessels. *See also* 1726 MED; 1847 MED.

❀ Physics

Charles François de Cisternay Du Fay (a.k.a. Duffay) [b. Paris, September 14, 1698, d. Paris, July 16, 1739] discovers that there are two types of static electric charges and that like charges repel each other while unlike charges attract. This leads to Du Fay's "two-fluid" theory of electricity, later opposed by Benjamin Franklin's "one-fluid" theory. Both have elements of truth. Du Fay's theory distinguishes

two types of electricity, which he calls vitreous and resinous, that are responsible for the phenomena of attraction and repulsion. *See also* 1731 PHY; 1734 PHY.

I Tools

John Kay [b. Bury, England, July 16, 1704, d. France, 1780] invents the flying shuttle loom, enabling weavers to produce much wider cloth at faster speeds than before. For the flying shuttle, boxes at each side of the loom are connected by a long board, known as a shuttle race. Cords are attached to a picking peg, enabling a single weaver, using one hand, to knock the shuttle back and forth across the loom from one shuttle box to the other. This invention is sometimes considered to herald the start of the Industrial Revolution. *See also* 1725 TOOL; 1745 TOOL.

1734

❀ Biology

René de Réaumur's *Mémoires pour servir à l'histoire des insectes* ("notes for a history of insects") is one of the founding works in entomology. *See also* 1669 BIO.

◊ Materials

Opera philosophica et mineralia ("philosophical and mineralogical works") by Emanuel Swedenborg is a three-volume survey of the nature of matter and of the laws of motion. The second and third volumes, *Regnum subterraneum sive minerals de cupro* ("copper") and *Regnum subterraneum sive minerals de ferrouso* ("iron"), describe min-

ing and smelting techniques. *See also* 1722 MATR.

Σ Mathematics

George Berkeley's *The Analyst: or, A Discourse Addressed to an Infidel Mathematician*, a work addressed to Edmond Halley, attacks Newton's calculus, calling infinitesimals "neither finite quantities, nor quantities infinitely small, nor yet nothing. May we not call them the ghosts of departed quantities?" *See also* 1693 MATH.

Euler's *Commentaries* from St. Petersburg introduces the notation $f(x)$ for functions. *See also* 1718 MATH.

❀ Physics

The French Académie des Sciences, suspicious of Newton's ideas for many years, awards a prize for the first time for a work based on Newton's theories.

Voltaire's *Lettres Anglaises ou philosophiques* ("English or philosophical letters") is the first introduction to Newtonian mechanics in French. *See also* 1687 PHY.

Charles Du Fay makes the first public report of the discovery that static electricity produces a shock — "one or more prickling Shoots, with a crackling noise that causes . . . A little Pain resembling . . . The burning from a Spark of Fire. . ." This discovery is later (1766) disputed by Anna Williams [b. England, 1706, d. 1783], who claims to have discovered the shock of static electricity about 1731 as an experimental subject for Stephen Gray. This seems to be contradicted by Gray's having given Du Fay in 1735 credit for the discovery. *See also* 1671 BIO; 1742 PHY.



The Enlightenment and the Industrial Revolution: 1735 through 1819

The term *Enlightenment* was coined to reflect a change in the philosophical approach from that of the preceding ages in which faith in God or faith in the authors of Antiquity was preeminent. During the Enlightenment, there was a critical examination of previous beliefs in the light of rationalism. The period of the Enlightenment is often equated with the latter part of the 18th century, starting with the works of Gotthold Ephraim Lessing in Germany and Denis Diderot in France, but this book is divided on the basis of scientific eras. Therefore, the next period begins with the Linnaean classification scheme, which represents scientifically the sense of order that characterized 18th-century thought, and terminates just before publication of the discovery of electromagnetism by Hans Christian Oersted in 1820. In England, the period from about 1740 to 1780 is the time generally considered the Industrial Revolution, which took place somewhat later in other Western nations. Thus, the Enlightenment and the Industrial Revolution overlap considerably.

Philosophy and science

One of the consequences of the revolution in science that took place during the 17th century was a profound change in philosophical thinking during the 18th century. The success of Isaac Newton's theories, the validity of which became well established during the first decades of the 18th century, not only had a profound impact on science itself, but also on philosophical outlook. New-

ton's success in explaining a large number of phenomena, such as falling bodies and the orbits of planets, by a simple set of laws encouraged people to view the physical sciences as a model for the other sciences. This resulted in the emergence of a "mechanical philosophy"; that is, the belief that not only physics but also chemistry and biology could be explained by sets of simple mechanical laws. Most attempts to apply Newtonian mechanics to problems in chemistry and physiology, however, were only partly successful during the 18th century.

The idea that mechanics would offer an explanation for all phenomena was taken the furthest by the materialistic philosophers of France such as Denis Diderot, Julien Offray de la Mettrie, and Baron d'Holbach. They denied the existence of a spiritual god and viewed nature entirely as a mechanical system. In this system, they included humanity itself, body and spirit. They believed that all physiological processes could be reduced to physical processes, but also that spiritual life, social processes, and even the course of history would fall under the same rules of nature.

Another factor that strongly influenced the philosophical outlook of the 18th century was the belief that nature embodied reason, and that the laws of nature would be reasonable laws.

Two approaches to philosophy in this period were empiricism — the idea that knowledge comes from experience — and rationalism — the view that knowledge comes from reasoning. A leading philosopher of the 18th century was Immanuel Kant, who coined the

term "Enlightenment." He reconciled empiricism and rationalism by saying that one can gain knowledge not only from experience but also from reasoning. The idea of causality — one event causing another to happen — a concept that David Hume rejected for many types of event — became for Kant an *a priori* concept, a general principle that cannot be proved but that has to be accepted as existing independent of our sense perceptions. Space and time, according to Kant, are also *a priori* concepts that are not accessible through the senses, but which condition our sense experiences of the physical world. Therefore, Kant argued, physics is not a science based only on sense experiences, but also on *a priori* concepts, making it possible to gain knowledge of the physical world using a rational system, such as mathematics.

This period also emphasized classifying the natural world in greater detail. Although classification schemes in science go back at least to the time of Aristotle (and are also a feature of all life in the most basic sense), and continue to be of importance today, we think of the later 18th century as a time when classification began to be put on a scientific basis, beginning, of course, with Linnaeus. But major efforts were also invested in classifying minerals as well as plants and animals of all sorts. Classification became a fundamental tool of science and part of its underlying philosophy.

Another philosophical idea that influenced science at this time had been revived by Gottfried Wilhelm Leibniz, although it had its roots in Plato and

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Aristotle. The Great Chain of Being, as this idea came to be known, envisioned all existence as continuous. For animals, for example, there was thought to be a continuous chain from the smallest flea to humanity, with no gaps. Some scientists of the Enlightenment, such as Comte de Buffon and Charles Bonnet, used this notion in their systems of classification, with Bonnet arguing that minerals graded into fossils, which were continuous with plants that, somewhere in the vicinity of the green hydra, became animals. At the end of the 18th century, Jean-Baptiste Lamarck used this concept in his theory of evolution. Not all scientists of the period accepted the Great Chain of Being. Georges Cuvier explicitly rejected it, for example.

Over the 18th century, this Great Chain of Being was gradually modified to include the concept of progress — that as time went on, higher beings arose. Various early theories of evolution reflected this notion as well.

The romantic reaction

The extreme materialism of some of the thinkers of the Enlightenment bothered many, and toward the end of the 18th century a new school of thought, often viewed as a romantic reaction to the materialism and rationalism of the philosophers of the Enlightenment, emerged in Germany: the school of *Naturphilosophie*. There was a similar reaction, generally called romanticism, in both France and England. The most prominent representatives of the *Naturphilosophie* school were the German poet and writer Johann Wolfgang von Goethe, who had also done considerable scientific work, Friedrich von Schiller, the philosopher Friedrich Wilhelm Joseph von Schelling, and the biologist Lorenz Oken. Instead of reason they preferred sentiment. Their view of nature was, to use a modern

term, holistic; that is, they believed that all nature should be viewed as a single organism and imbued with spirit. In France, Jean-Jacques Rousseau had expressed similar ideas somewhat earlier, especially in his emphasis on the importance of emotion.

In both France and the United States, political revolutions and the resulting new governments were heavily influenced by the philosophical trends of the time. Among the revolutionaries in the United States were the part-time scientists Benjamin Franklin and Thomas Jefferson. The scientists Joseph-Louis Lagrange and Pierre-Simon Laplace held posts in the revolutionary French government. In France even more than in the United States, there was an effort to remake the culture along “scientific lines,” including a short-lived reworking of the calendar and the creation of the influential metric system.

The Industrial Revolution

During the 18th century there was a general turn toward the development of machines that would make work faster or more efficient, especially in England. The motive for this surge of inventiveness is not completely clear. Some changes, such as the turn to coal for both heating and iron making, were caused by limitations in natural resources — in this case, wood. Trade certainly was a factor; for example the introduction of cotton from India and the United States. A new class, the capitalists, who were not really the same as the landowners, began to appear. They first bankrolled cottage industries but soon found it more practical to set up factories. For these and probably other reasons, the Industrial Revolution began. Because of its success in England, it was quickly taken up in those nations that were similar to England;

that is, in Europe, the United States, and Canada.

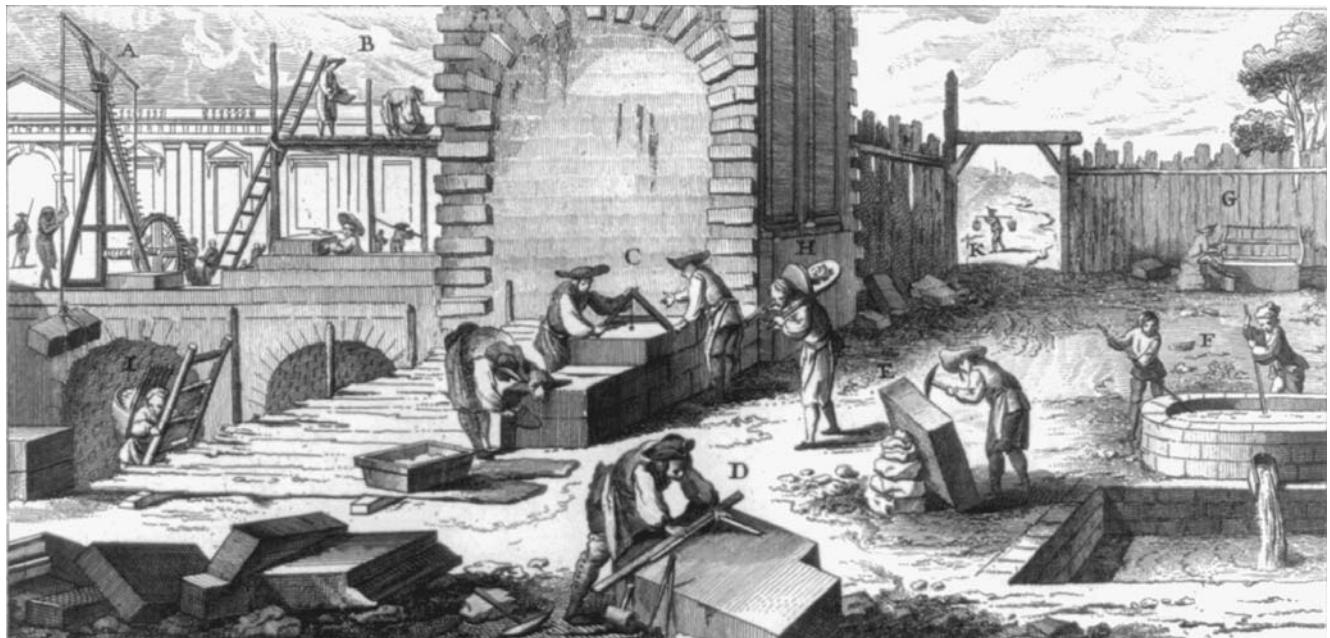
Influenced by technological developments, the Industrial Revolution in turn affected science. Interest in thermodynamics rose as a result of the steam engine. Such concepts as work and power began to be formalized, although this occurred mainly in the 19th century. A chemical industry based on inorganic reactions and not on such organic processes as fermentation slowly started. There was not much effect on life sciences, but industrialization did bring some new medical problems, mainly those connected with the workplace or with crowding.

The *Encyclopédie*

Around the same time, science and technology were also united in a new form of publication. Encyclopedias, such as Ephraim Chambers’s of 1728, Denis Diderot’s of 1743, Jacques Buot’s of 1761, the Britannica of 1771, and Friedrich Brockhaus’s of 1808 were all largely intended to bring the new technology to the masses and to combine the sciences and humanities.

The flagship publication of the Enlightenment was the French *Encyclopédie*. Edited by Denis Diderot and Jean le Rond D’Alembert, the 17 volumes of text and 11 of illustrations were published from 1751 to 1772. The *Encyclopédie* became important in the democratization of scientific knowledge. Technology was given equal importance to pure science and philosophy.

The *Encyclopédie* allowed the philosophers of the Enlightenment to communicate their ideas to a broader public. In keeping with the trend toward systematizing knowledge, another aim of the editors was to lay the foundations of all the arts and sciences. Unlike earlier encyclopedias, such as Ephraim Chambers’s *Cyclopaedia*, on which the *Encyclopédie* was



CRAFT OF MASONRY FROM DIDEROT'S *ENCYCLOPEDIE* The subtitle of the *Encyclopédie* is "a rational dictionary of science, arts, and crafts." Today it is especially valued by historians for its 11 volumes of illustrations, which show 18th century crafts, such as cutting and laying stone, in detail.

based, the *Encyclopédie* adopted a strong editorial point of view, opposing both church and state.

Rise of the engineer

The major technological breakthroughs and building enterprises before the Industrial Revolution were the work of amateurs, craftspeople, and military leaders. The profession of engineer was one of the great inventions of the 18th century. When we think of the great technological achievements of the 18th and early 19th centuries, the names that come to mind are sometimes those of inventors, such as Josiah Wedgwood or Joseph-Marie Jacquard, and sometimes those of such scientists as Nicolas LeBlanc, but primarily they are the names of engineers, especially British engineers: James Brindley, Marc Isambard Brunel, George Cayley, John Eric-

son, Robert Fulton, Henry Maudslay, John McAdam, William Murdoch, John Rennie, John Smeaton, George Stephenson, Thomas Telford, Richard Trevithick, James Watt, and John Wilkinson. Today we would class some of these people as mechanical engineers and others as civil engineers, but before the Industrial Revolution few such professions existed at all. The builders of the great French canals of the 17th century and of the Italian canals about 200 years earlier were among the first civil engineers, but they did not think of themselves this way. John Smeaton was the first person to call himself a civil engineer.

Civil engineering actually started in France three years before Smeaton set up shop on his own when, in 1747, the French government started a school of bridges and highways. By 1771 there were enough engineers in England for

them to begin to gather together on a regular basis in what was called the Smeatonian Club. France continued to provide the lead in engineering education, however, reorganizing the school of bridges and highways and starting the Ecole Polytechnique in the 1790s. In the early 19th century the Smeatonian Club led to the more formally organized Society of Civil Engineers in England, the first organization of its kind.

Major advances

ASTRONOMY Astronomy profited enormously from Newton's theory of gravitation and from advances made in mathematics. Astronomers predicted many astronomical phenomena with great precision. Pierre-Simon Laplace, often called the "French Newton," solved many mechanical problems and demonstrated the stability of the solar

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system. Astronomers and philosophers abandoned the Aristotelian idea that everything in the universe is static; that is, that since its creation, the universe always has looked the way it looks now. Kant and Laplace introduced the concept of the evolution of the universe and independently formulated a theory, known as the nebular hypothesis, for the origin of the solar system.

Better and more accurate telescopes led to the improvement of positional astronomy, the study of double stars, and the discovery of Uranus and several new planetary satellites. William Herschel was the first to propose that the Sun is a star belonging to a vast system of stars, now known as the Milky Way Galaxy. By counting the stars in different directions, he tried to determine the shape of the galaxy and found that it must be shaped like a millstone with the Sun at its center. Although Herschel was wrong about the details (we now think the Milky Way Galaxy is shaped like a spiral with the Sun far from the center), the basic idea of the Sun's belonging to a vast system of stars was right. Kant suggested that the many patchy objects visible in the telescope may be systems similar to the Sun's star system, an idea that was confirmed early in the 20th century.

BIOLOGY During the 18th century the classification of plants and animals was still viewed as part of "natural history," a science that also included the study of minerals, for example. Plant and animal physiology belonged to physics. In the *Encyclopédie*, zoology, botany, and medicine were categorized as fields of physics and came under the general heading of "reason." The approach to physiology was consequently mechanistic.

Carolus Linnaeus began the modern system of classification of living organisms and introduced the binary notation system for naming species that is still in use today. Comte de Buffon disagreed with Linnaeus's system of classi-

fication because he did not believe that a system based on external characteristics could be a natural system of classification. Buffon proposed a system based on the reproductive history of organisms instead. He said, for example, that a fox is a different species from a dog if and only if it can be shown that matings between a fox and a dog either produce no offspring or (as in matings between a mare and a jackass) sterile offspring.

Toward the end of this period, Georges Cuvier began to classify extinct species. Jean-Baptiste Lamarck studied in detail the anatomy of invertebrates. Both of these men contributed to the concepts that would lead to the theory of evolution in the 19th century, although Cuvier did not believe in evolution and Lamarck accounted for it with a now-discredited mechanism.

CHEMISTRY During most of the 18th century, chemistry was dominated by the erroneous phlogiston theory, which postulated a substance called phlogiston that produced the changes observed in burning. A large number of chemists adhered to this theory, which may account for the fact that chemistry advanced at a much slower pace than physics. The scientific revolution that for physics took place during the 17th century, happened in chemistry only at the end of the 18th century with the work of Joseph Priestley, Antoine-Laurent Lavoisier, Henry Cavendish, and John Dalton. Also, the number of technical applications was relatively small during the 18th century. A chemical industry did not flourish until the 19th century, when the mechanisms of chemical reactions were more fully understood.

Lavoisier proposed a correct theory of combustion at the end of the 18th century, opening the way to the rapid development of chemistry during the early years of the 19th century. At that time John Dalton put forth his atomic

theory, which eventually became the foundation of the new chemistry.

COMMUNICATION In addition to the development of the encyclopedia, the introduction of new societies of scientists and engineers and the opening of new colleges and universities continued at a steady pace. On the slightly more technical side, improvements in pens and the lead pencil contributed to writing by hand while various new inventions and applications of technology improved printing. A number of attempts were made to produce a practical telegraph based on electricity, but the underlying technology needed for success would not be ready until later in the 19th century.

CONSTRUCTION It is perhaps not surprising that the principal progress in architecture and construction during the Industrial Revolution centered on industry — canals, bridges, tunnels, and highways were built in profusion. The view of the Industrial Revolution in the United States, Canada, and England is heavily skewed toward events in England. Thus, we think of the Canal Age as starting in the second half of the 18th century, although the major canal building in France, even more extensive than in England or the United States, was a century earlier. Perhaps the greatest architectural achievements of this age, however, were English and American. These were the iron bridges, truss bridges, and suspension bridges that are among the wonders of the time. On the Continent, major bridges were built, but the finished product was not that different from Roman or Renaissance bridges. As with the canals, the main continental development (introduction of caissons, open at first at the top above the water line) preceded the beginning of the Industrial Revolution.

The first important iron bridge, built near the end of the 18th century over the river Severn in England, still stands.

About the same time in the United States wooden truss and suspension bridges began to be built.

EARTH SCIENCE One of the results of the Industrial Revolution was an increase in prospecting for coal and ores. This stimulated interest in the study of fossils and rocks, giving birth to a new science, termed *geology* by Horace de Saussure. Until the middle of the 18th century, it was generally believed that fossils and rocks were deposited by Noah's Flood, which, it was thought, had covered the whole planet. This was despite the fact that Robert Hooke had already shown that it was not possible that the thick layers of fossils could have been deposited in the 150 days the Flood was believed to have lasted. The French naturalist Buffon believed that Earth was much older than previous scientists thought — 80,000 years instead of 6000 years. The figure of 6000 years is a value obtained from the Old Testament, however, and was widely accepted. Buffon also rejected the idea that Noah's Flood was responsible for the existence of fossils, but he had to withdraw his writings because of opposition by the church.

Abraham Gottlob Werner, a professor of mineralogy at the Mining Academy of Freiberg, was the first to introduce systematic observation in the science of geology. He showed that rocks were formed layer by layer, with the oldest rocks at the bottom and the youngest ones on top. He argued that in the past Earth's surface was covered by a muddy sea and that Earth's crust was formed by deposition of suspended material. The crystalline rocks, such as granite or basalt, were, according to him, formed by the precipitation of minerals. His theory, called the *Nep tunist* theory, was opposed by the *Vulcanists*, who argued that the layers of rock in Earth's surface were formed exclusively by volcanic action, and the *Plutonists*, who emphasized the impor-

tance of heat from within Earth. James Hutton, who believed that some rocks were formed by volcanic action, also accepted sedimentation as a rock-forming process. His major contribution to geology was the insight that the surface of Earth was formed by the same forces that still are active today — mainly erosion and volcanism.

ENERGY The revolution in energy was perhaps the most astounding to people at the time. At the beginning of the Industrial Revolution, energy was drawn solely from natural sources — muscles, water, and wind. By the end of this period, steam engines were becoming the major source of power.

The introduction of the steam engine had an enormous influence on science as well as on manufacture and transportation. Engineers started measuring the efficiency of machines using scientific principles. The assessment of machines became a quantitative science.

FOOD & AGRICULTURE Ancient peoples had learned that food could be preserved by salting or pickling (or adding some other chemical preservative, such as alcohol or honey, which in many ways is the equivalent of pickling), by drying, or, where natural ice was available, by cooling. Variations of these methods were all that existed until the 19th century, when canning in glass jars or metal cans was invented. Canning works because microbes are killed by heat and a tight seal prevents air from entering sterilized containers. Canning quickly became one of the main ways to preserve food, as it still is today. For one thing, canning does not alter the taste and texture of food as much as pickling and drying do.

MATERIALS At the beginning of the Industrial Revolution there was wrought iron and precious steel and no other hard metal of significance in Europe, although China had known the secret of cast iron for centuries. By the

end, cheap steel was the metal of choice for machinery and building. Wrought iron, although made much more cheaply and easily by the end of the 18th century, was almost all reserved for specialty purposes and cast iron was used only where its brittleness was not a deciding issue.

All this iron and steel would have been impossible without the substitution of coke for increasingly scarce charcoal. In the middle of the 18th century, a lucky combination of a source of low-phosphorus coal (phosphorus makes iron alloys brittle) and a strong foundry tradition enabled Abraham Darby to be the first to succeed in making a commercial success of coke-fired cast iron.

Consequently, the demand for coke led throughout this period to better and better methods of producing that commodity. As important consequences of coke production, coal gas, a byproduct of coke production, became the first good source of outdoor urban lighting and the production residue called coal tar became the basis of much of the organic chemical industry of the late 19th and early 20th centuries.

Carbon-based organic chemicals were not the whole story, however. This was the period when the first major inorganic chemicals (other than metals) moved out of the laboratory and into industry. These included sulfuric acid in 1746 and, in 1783, the start of industrial production of sodium hydroxide, sodium carbonate, and oxymuriatic acid (later identified as chlorine).

MATHEMATICS The introduction of calculus by Newton and Gottfried Wilhelm Leibniz had caused mathematics to develop rapidly into a tool eminently suited for dealing with problems of theoretical mechanics. The convenient and suggestive notations of Leibniz and those used by Leonhard Euler were accepted in continental Europe. In England Newton's notation was used

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throughout this period, resulting in slower advances for British mathematics as compared with that of the Continent. The wholesale application of calculus to physical problems, initiated by the Bernoulli brothers early in the 18th century, was continued by Euler, D'Alembert, and Lagrange. Euler and Lagrange created the calculus of variations. Lagrange introduced the differential equations now called Lagrangians, which could be used to represent Newton's laws of motion in a more generalized form. Laplace applied Newton's theory of gravitation and calculus to astronomy in detail, furthering the field of celestial mechanics. A new mathematical field, statistics, initially developed by Jacques Bernoulli, was further refined by Abraham De Moivre and Laplace.

MEDICINE & HEALTH Several important developments occurred in the medical sciences. A significant advance in physiology was the publication of Albrecht von Haller's medical encyclopedia, *Elementa physiologiae*, started in 1757. This was the beginning of modern physiology as an independent science. François-Xavier Bichat founded histology — the study of tissues of living things — around 1800. Edward Jenner introduced vaccination to prevent smallpox at the end of the 18th century, the first successful method in medicine for fighting disease on a large scale.

New tools for diagnosis included the ones most commonly used in a routine examination today: thermometers for body temperature, a stethoscope and thumping to listen to the heart and lungs, and early devices for measuring blood pressure. Dentists acquired the drill and became better at making and installing false teeth when the drill and various fillings, some invented during this period, failed to suffice.

PHYSICS The developments in the science of mechanics were mainly the

result of advances in mathematics. Newton's physics was finally accepted in France because it successfully predicted that Earth would be flattened at the poles and also correctly predicted the return of Comet Halley.

However, Newton's physics could only handle problems that treated masses as single points, the centers of gravity. Such a limitation is acceptable for the calculation of planetary orbits, but not useful in many other cases. Leonhard Euler first introduced the generalized coordinates of a body, a mathematical system that allows the whole motion of an extended system, such as a pair of scissors flying through space, to be analyzed. The individual motions of each half of the scissors could be accounted for instead of just the motion of the center of gravity of the scissors. Lagrange improved on Euler's coordinate system so that it could be applied to systems of several moving bodies taken all at once. He also gave a proof that the principle of least action (for example, that the kinetic energy takes on a minimum value when bodies are left moving freely) could be derived from Newton's laws of motion.

Count Rumford cast doubt on the commonly accepted solution to a problem that had intrigued scientists throughout the century: the nature of heat. Heat was generally viewed as a kind of fluid by most 18th-century scientists. Rumford measured the amount of heat produced by boring a cannon, which was enormous. He did not think that the cannon could contain so much caloric, the purported fluid. Instead, since heat was being produced by motion, he suggested that heat is a form of motion itself. Although he failed to convince many then, later studies showed him to be right.

The 18th century was also a period of extensive experimentation with elec-

tricity, although the nature of electricity remained largely a mystery.

TOOLS While many of the changes we associate with the Industrial Revolution concern energy, materials, or transportation systems, none would have been possible without the development of new tools for production and operation. The advent of machine tools, including devices for precision boring, greatly improved lathes, the steam hammer, and sets of machine tools for specific purposes, helped make everything else possible. Near the end of the period, the American inventor Eli Whitney introduced standardized parts into technology, providing a major change in the way products are manufactured.

The fabric industry drove a lot of the invention and industry of the Industrial Age, starting with the widespread adoption of the flying shuttle some years after its invention, and followed by such colorfully named devices as the jenny and the mule. The whole production process of some fabrics was gradually mechanized, from carding and combing wool to spinning of fibers through weaving or knitting. Although we think of England as the great fabric manufacturer, the development of automatic control systems, which later influenced early computers, took place in France.

It was generally understood that the teaching of science and technology is an important part of the technological development of a country and several engineering schools were established throughout Europe. The Ecole Polytechnique in Paris, founded in 1794, became an important source of talent for the development of science in France during the 19th century.

TRANSPORTATION As with other areas, transportation showed remarkable progress on all fronts, except perhaps for highways, still muddy ruts for most

of the period (although gravel roads were introduced by McAdam). People and goods traveled largely by water (including on canals as well as natural waterways), on rails, in horse-drawn car-

riages, and in carriages drawn by the steam-powered locomotives. The more adventurous even flew through the air in balloons.

Putting steam engines on carriages was the other logi-

cal step. This worked best when the carriages were on iron rails (even small steam engines are heavy, their fuel is heavy, and the water in their boilers is heavy). Steam-powered railroads

were faster by far than the canals, and cheaper to build. Soon they had not only taken away virtually all passenger traffic, but also all but the bulkiest freight.

CHRONICLE

1735

生物学

Systema naturae (“system of nature”) by Carolus Linnaeus introduces the system of classification for organisms that is still in use today.

Benoit de Maillet [b. St. Mihiel, Lorraine, France, April 12, 1656, d. Marseilles, France, January 13, 1738] writes *Telliamed* (“de Maillet” spelled backward), in which he advances an evolutionary theory based on Earth having originally been covered with an ocean. In this theory, as the waters slowly evaporated and exposed land, creatures were caught in the mud and formed fossils. De Maillet thinks that the universe is filled with “seeds” that grow into animals in the sea; as the sea gradually diminishes, some of these creatures evolve into land animals. Although he recognizes strata containing different fossils and observes a progression in complexity, he turns to myths and fancy when it comes to human evolution. When the work is published posthumously (the first edition ten years after his death) it will scandalize orthodox Christians — but will go through several editions. The English



Carolus Linnaeus

[b. Råshult, Sweden, May 23, 1707, d. Uppsala, Sweden, January 10, 1778] The 1735 publication of *Systema naturae* established the fame of Linnaeus with an organized classification structure for all living things. The binomial system of nomenclature, now the basis for naming and classifying all organisms, was first introduced by Linnaeus in 1749. In his *Species plantarum* in 1753 Linnaeus attempted to name and describe all known plants, calling each kind a species and assigning to each a two-part Greek or Latin name consisting of the genus (group) name followed by the species name. Many of his names of flowering plants survive with little if any change — for example, *Quercus alba* for white oak. The 1758 edition of *Systema naturae* extended binomial classification to animals.

edition will be called *Telliamed; or, the Worrlid Explain'd . . . — A Very Curious Work*. See also 1751 BIO.

Georges Louis Leclerc, Comte de Buffon [b. Montbard, France, September 7, 1707, d. Paris, April 16, 1788] translates *Vegetable Staticks* of Stephen Hales into French.

通信

Charles III of the Austro-Hungarian Empire starts a mining officer's school at Selmecbánya, better known as Schemnitz (Banská Štiavnica, Slovakia), the world's first technical college. The Schemnitz Mining Academy is today known as the University of Miskolc. See also 1747 COMM.

地球科学

English lawyer and meteorologist George Hadley [b. 1685, d. 1768] describes the Hadley Cell, which models Earth's wind circulation. Winds from

about 30° latitude blow near Earth's surface toward the equator, where heat makes air rise. Cooler air descends at about 30° latitude to replace that moving toward the equator, implying that there is a flow at higher altitudes from the equator toward the poles. See also 1747 MATH.

Charles-Marie de la Condamine leads an expedition to Peru to measure the curvature of Earth at the equator.

Johann Georg Gmelin [b. Tübingen, Württemberg (Germany), August 10, 1709, d. Tübingen, May 20, 1755] discovers permafrost, which is a layer of soil containing considerable water that remains frozen all year, on a voyage to Siberia.

材料

Naval officer Antonio de Ulloa [b. Seville, Spain, January 12, 1716, d. Cadiz, Spain, July 5,

1795] is the first to call European attention to platinum (Pt) as a previously unrecognized element. See also 1550 MATR.

Charles-Marie de la Condamine sends Europe samples of natural rubber and curare from Peru. See also 1731 MATR.

物理学

L'optique des couleurs (“optics of colors”) by Jesuit monk Louis Bertrand Castel [b. France, 1688, d. Paris, January 11, 1757] is a scheme for making colors and musical notes correspond.

A simplified version of Newton's optics, *Newtonianismo per le dame* (“Newtonianism for the ladies”), by Francesco Algarotti [b. Venice, Italy, 1712, d. Pisa, Italy, 1764] becomes one of the most popular explanations of Newton's physics. See also 1738 PHY.

Cast iron in England

In Europe there was no apparent single discovery of cast iron and, unlike many innovations at the end of the Middle Ages, cast iron as a concept seems not to have reached Europe from China.

Instead, forge designs were gradually improved to produce hotter and hotter fires. Some forges built in Austria in the late 13th or early 14th century were hot enough to melt the iron they produced. Improvements on these became early blast furnaces.

The European adoption of cast iron meant that availability of ore no longer determined the amount of metal that would be produced. Instead, the limiting factor soon became the availability of wood for charcoal. England, for example, had lost most of its forests by 1600, in large part because of iron smelting.

Coal, another product that had a much longer history in China than in the West, seemed to many to be the solution to the problem. Starting late in the 16th century in England, where coal was already a common fuel, iron makers attempted to use coal for iron instead of charcoal. Most of them failed, although some claimed success. Early in the 18th century, however, Abraham Darby in western England found out how to make high-quality cast iron using coke, coal that has been heated to drive off its gaseous form various impurities.

The grandson of Abraham Darby, also named Abraham Darby, demonstrated that cast iron made from coke could be used even in large bridges. Furthermore, the ease of making molds and specific shapes from cast iron led to the many different parts that were needed for the Industrial Revolution.

Transportation

John Harrison, in response to the award put up by the British Board of Longitude in 1714, builds his first marine chronometer, known as Number One; each of his prototype chronometers is given a similar designation, with Number Four being the most famous. *See also* 1714 TRAN; 1759 TRAN.

1736

Archaeology

Charles IV of Two Sicilies [b. Italy], 1716, d. 1788; later Charles III of Spain] purchases the land at Ercolano where Roman statues have been found and sends Marcello Venuti, the Royal Antiquary, down shafts to find their source. Venuti discovers the ruins of the ancient city of Herculaneum. *See also* 1705 ARCH; 1748 ARCH.

Chemistry

Sur la base du sel marin (“on the composition of sea salt”) by Henri Louis Duhamel du Monceau [b. Paris, July 1700, d. Paris, August 13, 1782] makes the first distinction

between sodium and potassium salts.

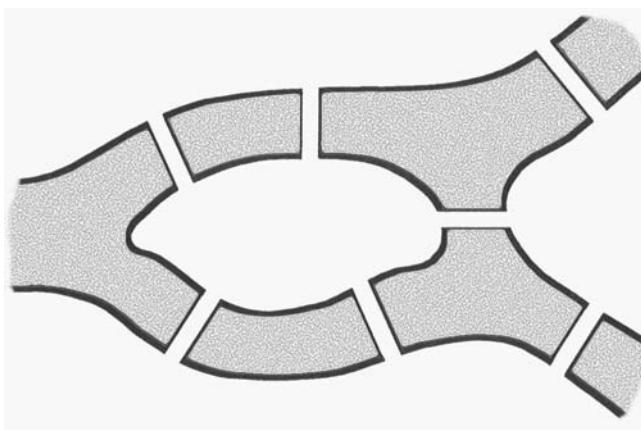
Earth science

Pierre de Maupertuis leads a French expedition sponsored by the Académie Francaise to Lapland, accompanied by Alexis Clairaut and Anders Celsius, to measure the length of a degree. His results prove that Earth is flattened at the poles, which shows that Newton’s theory of gravity is correct and Descartes’ theory is false. *See also* 1718 EAR; 1738 EAR.

Mathematics

John Colson’s English version of Isaac Newton’s *De methodis serierum et fluxionum* (“the method of infinite series and fluxions”) is the first published version of Newton’s theory of fluxions (originally written in 1671), Newton’s version of the calculus. *See also* 1671 MATH.

Euler publishes his solution to the problem of the bridges of Königsberg. He shows that with the configuration of seven bridges that use two islands as well to connect the banks of the river, it is not



THE SEVEN BRIDGES OF KÖNIGSBERG In the 18th century, the gentle folk of Königsberg (Kалининград, Russia) strolled the city and debated whether one could cross each of the seven bridges exactly once in a single walk. In the diagram, land regions and bridges are white, the river gray. Euler proved the single-traverse walk impossible, the beginnings of both network theory and topology in mathematics.

possible to stroll all the bridges without crossing one of them twice. This is the first application of what we now call network theory (sometimes known as graph theory) and a precursor to topology.

Euler’s *Mechanica sive motus scientia analytic exposita* (“explanation of mechanics based on analysis”) is the first systematic textbook on

mechanics to be based on differential equations. *See also* 1696 MATH; 1769 MATH.

Medicine & health

American physician William Douglass [b. Scotland, 1691, d. 1752] describes scarlet fever.

Claudius Aymard performs the first successful operation for appendicitis. *See also* 1822 MED.

1737

★ Astronomy

On May 28 John Bevis, at Greenwich Observatory, observes the passage of Venus directly between Earth and Mercury, known as the occultation of Mercury by Venus.

Biology

Carolus Linnaeus's *Genera plantarum* explains his method of systematic botany and classifies 18,000 species of plants. *See also* 1789 BIO.

Hermann Boerhaave prints Jan Swammerdam's *Biblia naturae* ("Bible of nature"), written from 1676 through 1679. It contains Swammerdam's reports on the dissection of insects under a microscope, which formed *Historia insectorum generalis* ("general history of insects") in 1669, as well as much new material from research in the 1670s. Although *Biblia naturae* was not published during Swammerdam's lifetime — he will die in 1680 — much of the content had become well known to European biologists from letters and manuscript copies. *See also* 1775 BIO.

Communication

Göttingen University is founded.

Pierre Simon Fournier [b. Paris, September 15, 1712, d. Paris, October 8, 1768] introduces the point system for measuring type sizes. *See also* 1764 COMM.

Construction

Bernard Forest de Bélidor publishes the first volume of his four-volume *Architecture*

hydraulique ou l'art de conduire, d'élever et de ménager les eaux pour les besoins de la vie ("hydraulic architecture, or the art of moving, lifting, and managing water for life's needs"), a manual that will influence building design and practice for more than a century. It is the first book to apply the integral calculus to practical construction problems. The set will be completed in 1753.

Mathematics

Euler proves that the number e , known as the base for the natural logarithms, and its square are both irrational; that is, they cannot be represented by finite or repeating decimals. *See also* 1768 MATH.

Physics

Pieter van Musschenbroek publishes *Essai de physique* ("essay on physics"), one of the first books of the era using the term "physics" instead of natural or experimental philosophy. The term *physics*, however, goes back at least to Aristotle.

1738

★ Astronomy

Joseph Nicolas Delisle [b. Paris, April 4, 1688, d. Paris, September 11, 1768] tracks the location of sunspots using heliocentric coordinates.

Biology

Ichthyologia sive opera omnia de piscibus scilicet ("ichthyology, or all about fish") by Petrus (Peter) Artedi [b. Angermanland, Sweden, February 27, 1705, d. Amsterdam, Holland, September 27, 1735], edited by Linnaeus and pub-

lished posthumously, establishes Artedi's reputation as the father of ichthyology for its taxonomy of fishes.

Communication

William Warburton [b. Newark, England, December 24, 1698, d. Gloucestershire, England, June 7, 1779] argues that writing originally developed from pictographs, which over the course of time became simplified into script. *See also* 1603 COMM.

Construction

Charles Dangeau de Labelye employs the caisson, a device essential to building bridges and underwater tunnels, for a bridge over the Thames at Westminster, England.

Earth science

Pierre de Maupertuis' *Sur la figure de la Terre* ("on the shape of the Earth") reports his measurements made in Lapland, confirming that Earth is flattened at the poles. *See also* 1736 EAR.

Mathematics

The second edition of Abraham De Moivre's *Doctrine of Chances: or, a Method of Calculating the Probability of Events in Play* introduces Stirling's formula for approximating factorials. The basic formula had been previously discovered by De Moivre, but James Stirling found the value of a missing constant.

Physics

Daniel Bernoulli's *Hydrodynamica* ("science of fluid motion") explains the relationship between the pressure and velocity of fluids, including the idea of the law named

after him, in terms of impact of atoms on the walls of a container. Bernoulli's law is that a flowing fluid maintains a constant sum of energy and pressure (so increasing speed lowers pressure). This law is the precursor of the kinetic theory of gases.

Voltaire's *Éléments de la philosophie de Newton* ("elements of Newton's philosophy"), written with the help of Madame du Châtelet, introduces English empirical philosophy to the Continent. *See also* 1735 PHY.

Tools

Spinning using rollers is introduced. *See also* 1530 TOOL; 1764 TOOL.

Jacques de Vaucanson completes an automaton consisting of a flute player that plays a tune on a real flute; a mechanism moves the lips and fingers and pumps air through the mouth. *See also* 1615 TOOL.

1739

★ Astronomy

Notes on Sunspots by John Winthrop [b. Boston, Massachusetts, December 19, 1714, d. Cambridge, Massachusetts, May 3, 1779] is the first set of such observations in the Massachusetts colony.

Communication

The Royal Society of Edinburgh is founded in Scotland.

A scientific society is founded in Stockholm, Sweden, by Linnaeus and others; in 1741 it becomes Kungliga Svenska Vetenskapsakademien.

Introducing Newton to the French

In England, Newton's *Principia* was generally accepted for the explanation of gravitation and the motions of celestial bodies. In France, however, Descartes' theory of vortices was still favored over Newton's theory of gravitation. One of the people instrumental in disseminating Newton's theory of gravitation to Europe was the French writer and philosopher Voltaire.

After having twice spent some time in the Bastille for writing witty verses against the French authorities, Voltaire went to England. There he found a society that he considered more rational than the French one. He also acquainted himself with the physics of Newton.

In 1734 Voltaire published an account of his stay in England, his *Lettres philosophiques* ("philosophical letters"), in which he dedicated a large section to Newton's theory of gravitation. For

many French readers this was their first exposure to Newton's physics, although it was 50 years after the publication of the *Principia*. Because the *Lettres philosophiques* contained criticism of the French government, Voltaire was forced to leave Paris again. He settled with Madame du Châtelet in her chateau at Cirey and started writing his *Éléments de la philosophie de Newton* ("elements of Newton's philosophy"), which was published in 1738. Madame du Châtelet started writing her own book on physics, *Institutions de physique* ("school of physics"). Unlike Voltaire, she was more influenced by Leibniz than by Newton, and her book made Leibniz's work, which was in German, known to the French.

Madame du Châtelet started translating Newton's *Principia* in 1747. She died in childbirth as she was finishing the translation in 1749. Her translation is still the only one of the *Principia* ever attempted in French.

❖ Energy

John Clayton describes to the Royal Society his experiments in producing a close analog to natural gas by distillation of coal (later this product becomes known as coal gas). *See also* 1850 ENER.

♥ Medicine & health

David Hume [b. Edinburgh, Scotland, April 26, 1711, d. Edinburgh, August 8, 1776] publishes *Treatise of Human Nature*, an attempt to apply the experimental method to problems of psychology and human nature.

✿ Physics

George Martine demonstrates that the amount of heat contained in an object is not proportional to its volume. *See also* 1781 PHY.

I Tools

In Geneva, Switzerland, cannon are first built by the process of casting a solid cylinder of metal and boring out the inside of the cylinder

to make a chamber. *See also* 1542 TOOL; 1774 TOOL.

1740

★ Astronomy

James Short [b. Edinburgh, Scotland, June 10, 1710, d. June 15, 1768] builds telescopes to Jacques Cassegrain's design. *See also* 1672 AST.

■ Construction

The western towers of Westminster Abbey in London, designed by Christopher Wren, are completed after his death.

● Earth science

De'crostacei e degli altri corpi marini che si trovano su' monti

("on crustaceans and other sea creatures found on mountains") by Antonio Lazzaro Moro [b. 1687, d. 1764] is an important study of marine fossils. Moro proposes that volcanic action lifted mountains out of the sea beds. *See also* 1793 EAR.

I Tools

Dutch engineers develop a cannon with a shorter tube that can easily be loaded by hand; the English name for cannon of this type is howitzer, a corruption of the German name. *See also* 1739 TOOL.

1741

✿ Biology

Steller's sea cow is discovered

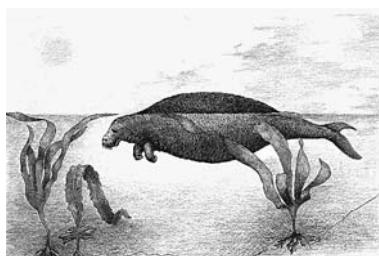
by scientists for the first time, living off the coast of the Kamchatka Peninsula (Russia). Only 27 years later it will have been hunted to extinction. *See also* 1733 EAR.

● Earth science

Alexi Ilich Tschirikov and Vitus Jonassen Bering discover the Aleutian Islands and the coast of Alaska during the Russian Great Nordic Expedition. *See also* 1733 EAR.

I Tools

About this time Antoine Thiout [b. near Vesoul, France, 1692, d. unknown] designs a lathe that can make screws automatically and that can be adjusted to various pitches. *See also* 1760 TOOL.



EXTINCT STELLER'S SEA COW There were probably only a few thousand of these giant relatives of the manatee when they were discovered by a Russian explorer's expedition. The last sea cow was killed and eaten in 1768 by Russian sailors.

1742

Biology

Abraham Trembley [b. Geneva, Switzerland, September 3, 1710, d. Geneva, May 12, 1784] experiments with the polyp, a small freshwater animal now called the hydra. Trembley had previously believed it to be a plant. He shows that it can be cut into small pieces, each of which can be regenerated into the entire creature. *See also* 1744 BIO.

Communication

The Royal Danish Academy of Sciences and Letters is founded at Copenhagen by Christian VI.

Materials

Benjamin Huntsman [b. Lincolnshire, England, 1704, d. 1776] introduces the crucible process for molten steel about this time. The cast steel is the hardest known to date and is at first rejected by English manufacturers as too hard, although it becomes acceptable in England after the French demonstrate its benefits.

Mathematics

German-Russian mathematician Christian Goldbach [b. Königsberg (Kaliningrad, Russia), March 18, 1690, d. Moscow, November 20, 1764] in a letter to Euler, suggests that every even number greater than 2 is the sum of two prime numbers (alternatively, every even number greater than 4 is the sum of two odd primes). Goldbach's conjecture has resisted all attempts at proof or disproof. *See also* 2000 MATH.

Treatise on Fluxions by Colin Maclaurin treats calculus on the basis of Greek geometry.

Physics

John Théophile Desaguliers [b. La Rochelle, France, March 12, 1683, d. London, March 10, 1744] repeats and extends Stephen Gray's experiments with electricity and introduces the words *conductor* and *insulator*. *See also* 1729 PHY.

Tools

Microscope Made Easy by Henry Baker [b. London, May 8, 1698, d. London, November 25, 1774] introduces the construction and use of the microscope to the layman. *See also* 1675 TOOL; 1792 TOOL.

Anders Celsius invents the Celsius scale (centigrade thermometer); in his original version, he uses 0 for the boiling point of water and 100 for the freezing point. Jean Pierre Christin [b. 1683, d. 1755] switches these in 1743 to give the system we use today. *See also* 1794 TOOL.

English mathematician and engineer Benjamin Robins [b. Bath, England, 1707, d. Madras, Spain, 1751] helps found the science of ballistics in his *New Principles of Gunnery*, which describes his invention of the ballistic pendulum. *See also* 1537 PHY.

Jacques de Vaucanson writes a report comparing industrial methods in silk manufacture in Piedmont and France. Attempts to implement new manufacturing rules based on Vaucanson's findings lead to strikes and social unrest in Lyon. *See also* 1810 TOOL.

1743

Communication

Benjamin Franklin is instrumental in establishing the

American Philosophical Society at Philadelphia, the United States' first scientific society.

Jean-Paul de Gua de Malves [b. Carcassone, France, 1713, d. Paris, June 2, 1785] and Englishman John Mills begin development of a version of Ephraim Chambers's English *Cyclopaedia*. *See also* 1728 COMM; 1747 COMM.

Earth science

Théorie de la figure de la terre, tiré des principes de l'hydrostatique ("theory of the shape of the Earth based on the principles of hydrostatics") by Alexis Claude Clairaut [b. Paris, May 7, 1713, d. Paris, May 17, 1765] shows that Earth is flattened at the poles and shows how to compute gravitational force at any latitude. *See also* 1672 EAR.

Cartographer Jean-Baptiste d'Anville [b. Paris, 1697, d. Paris, January 28, 1782] produces his *Map of Italy*. *See also* 1744 EAR.

Christopher Packe [b. 1686, d. 1749] produces *A New Philosophical Chart of East Kent*, the first geological map. *See also* 1794 EAR.

Physics

Traité de dynamique ("treatise on dynamics") by Jean le Rond D'Alembert [b. Paris, November 16, 1717, d. Paris, October 29, 1783] deals with the implications of Newton's laws of motion and introduces D'Alembert's principle to physics. D'Alembert's principle is that in a closed system of moving bodies, the external forces and inertial forces are in equilibrium. The book applies the principle to the solution of prob-

lems in mechanics. *See also* 1687 PHY.

1744

Astronomy

Swiss astronomer Jean Philippe Loys de Cheseaux [b. 1718, d. 1751] restates the problem known as Olbers's paradox (from Heinrich Olbers's later version): Why is the sky dark? If the number of stars is infinite, a stellar disk should cover every patch of the sky. Cheseaux claims that a slight loss of light as it travels through space solves the problem. *See also* 1826 AST.

The Roman Catholic Church, while leaving Galileo's *Dialogue Concerning the Two Chief World Systems* on the Index of Prohibited Books, allows it to be printed as long as Galileo's recantation of Copernican theory is included in the same volume. *See also* 1632 AST.

Biology

Abraham Trembley's *Mémoires Concerning the Natural History of a Type of Freshwater Polyp with Arms Shaped Like Horns* summarizes his research on the hydra and his discovery of regeneration in polyps. *See also* 1742 BIO.

Earth science

César-François Cassini [b. Thury, France, June 17, 1714, d. Paris, September 4, 1784] directs the triangulation of France, the first national geographic survey, resulting in the first map produced according to modern principles. *See also* 1743 EAR.

↗ Energy

Francis Hauksbee demonstrates that the glow of an electric discharge can be used to provide a safer light in mines. *See also* 1709 ENER.

Benjamin Franklin invents the “Franklin stove” about this time. *See also* 1732 EAR.



Mikhail Vasilievich Lomonosov

[b. Denisovka, Russia, November 8, 1711, d. St. Petersburg, Russia, April 15, 1765]

Although little known among English-speaking nations, Lomonosov is recognized as a great author and scientist in Russia — he even has a large naval vessel named for him. He created the system of higher education in Russia and made Moscow University possible; in 1940 the university was renamed the M.V. Lomonosov Moscow State University. Lomonosov also was a first-rate poet and writer of fiction. As a scientist he anticipated many discoveries attributed in the West to much later physicists, geologists, astronomers, and inventors.

❖ Materials

Euler succeeds in calculating the length of a rod that will buckle under its own weight when stood on one end. *See also* 1798 MATR.

Σ Mathematics

Euler's *Methodus inveniendi lineas curvas maximi minimive proprietate gaudentes* (“the art of finding curved lines that enjoy some maximum and minimum property”) generalizes some basic methods of the calculus of variations, the mathematical study of maximum and minimum functions. It includes Euler's equation, which describes a necessary condition that a function is a minimum. *See also* 1718 MATH; 1755 MATH.

Euler's *Theorium motuum planetarium et cometarium* (“theory of the motions of planets and comets”) is a precursor to the more exact calculations of orbits of Lagrange. *See also* 1788 PHY.

♥ Medicine & health

English surgeon William Cheselden breaks with the barber surgeons and sets up a private anatomy school for medical surgeons. The success of his school soon inspires seven similar schools in London.

✿ Physics

Jean le Rond D'Alembert's *Traité de l'équilibre et du mou-*

vement des fluides (“treatise on the equilibrium and motion of fluids”) uses his principle to describe fluid motion. *See also* 1743 PHY.

Pierre de Maupertuis originates the Principle of Least Action. Action is a quantity that is essentially force multiplied by distance and time. The principle states that nature operates in such a way that action is at a minimum. Experiments continue to demonstrate that the rule holds in all known situations. *See also* 1788 PHY.

Chemist and writer Mikhail Vasilievich Lomonosov publishes a paper on the causes of heat and cold, correctly thinking heat is a form of motion. *See also* 1798 PHY.

↗ Transportation

English sea captain John Seson is the first to attempt to use a gyroscope for steering at sea, but the experiment fails and he loses his life when the ship founders. *See also* 1576 TRAN; 1852 TRAN.

1745

✿ Biology

Traité d'insectologie (“treatise on insectology”) by Charles Bonnet [b. Geneva, Switzerland, March 13, 1720, d. Genf, Switzerland, May 20,

1793] describes his observations on parthenogenetic reproduction and metamorphosis of aphids.

⊕ Earth science

Mikhail Lomonosov publishes a catalog of 3030 minerals. *See also* 1758 CHEM.

Comte de Buffon proposes that Earth was formed when a comet collided with the Sun. *See also* 1749 EAR.

↗ Energy

Edmund Lee invents the fantail or fly, also called the rosette, a small windmill at right angles to the main windmill that turns the top cap so as to keep the main sails facing the wind.



FANTAIL DIRECTING WINDMILL'S TURRET The Dutch introduced windmills that have movable turrets, but originally a human operator was needed to rotate the turret to point the sails into the wind. The fantail points the turret automatically in the proper direction without the need of human intervention.

❖ Materials

Gowin Knight [b. Corringham, England, 1713, d. June 8, 1772] invents a method for preparing magnetized steel.

I Tools

Jacques de Vaucanson invents the self-acting, tape-controlled loom for weaving silk. *See also* 1733 TOOL; 1775 TOOL.

1746

⌚ Communication

Pensées philosophiques (“philosophical thoughts”) by Denis Diderot [b. Langres, France, October 5, 1713, d. Paris, July 31, 1784] attempts to demonstrate the existence of God through the order of nature.

Princeton University is founded in New Jersey.

John Winthrop establishes the first laboratory for experimental physics in the United States at Harvard University in Massachusetts.

⊕ Earth science

Jean-Etienne Guettard [b. Etampes, France, September 22, 1715, d. Paris, January 6, 1786] draws the first geological map of France, although it does not detail strata. *See also* 1743 EAR; 1763 EAR.

☛ Energy

In January the Leiden jar — the first practical way to store static electricity — is invented. The invention is made at about the same time by both Pieter van Musschenbroeck and by Ewald Georg von Kleist [b. c. 1700, d. Köslin, Pomerania (Poland), December 11, 1748]; Van Musschenbroeck gets a shock (literally) when he first uses it, suggesting a connection between electricity and lightning. *See also* 1775 ENER.

Experiments on the Nature of Electricity by physician William Watson [b. London, April 3, 1715, d. London, May 10, 1787], published over the next two years, describes Watson's experiments with the Leiden jar.

❖ Materials

Inventor John Roebuck [b. Sheffield, England, 1718, d. July 17, 1794] introduces the lead-chamber process for the manufacture of sulfuric acid.

♥ Medicine & health

The compressive bandage to stop bleeding from wounds is introduced. *See also* 1869 MED.

* Physics

About this time Euler works out the mathematics of the refraction of light by assuming that light is a wave phenomenon in which colors correspond to different wavelengths, as had been proposed by Christiaan Huygens in 1678 (published in 1690). *See also* 1678 PHY; 1801 PHY.

1747

* Astronomy

Alexis Clairaut's *Théorie de la lune* ("theory of the Moon"), published this year, wins the 1750 prize of the Academy of

Saint Petersburg. It is the first approximate resolution of the three-body problem, which is the mathematically intractable problem of finding how three different masses interact with each other in space (for example, the Sun, Earth, and Moon). *See also* 1749 AST.

☛ Communication

Denis Diderot becomes editor of what will become the *Encyclopédie*, assisted by Jean le Rond D'Alembert and replacing Jean-Paul de Gua de Malves. Originating as a French version of Ephraim Chambers's *Cyclopaedia*, the new project is completely reworked and expanded, becoming the most important work of the Enlightenment. It will be completed in 1772. *See also* 1743 COMM; 1751 COMM.

The first civil engineering school, the *Ecole des ponts et chaussées* ("school for bridges and highways"), is established in France. *See also* 1771 COMM.

॥ Food & agriculture

Chemist Andreas Marggraf [b. Berlin, March 3, 1709, d. Berlin, August 7, 1782] discovers sugar in beets, laying the foundation for Europe's sugar-beet industry. *See also* 1503 FOOD; 1802 FOOD.

Σ Mathematics

Jean le Rond D'Alembert's *Réflexions sur la cause générale des vents* ("on the general theory of the winds") contains the first general use of partial differential equations in mathematical physics. *See also* 1735 EAR; 1814 MATH.

♥ Medicine & health

Tabula sceleti et musculorum corporis humani ("plates of the skeleton and muscles of

the human body") by German anatomist Bernhard Siegfried Albinus [b. 1697, d. Leiden, Holland, September 9, 1770] shows relative parts of bones and muscles in correct proportions. *See also* 1543 MED.

❀ Physics

Jean le Rond D'Alembert publishes his theory of vibrating strings, giving the general solution of the partial differential wave equation in two dimensions.

Abbé Jean-Antoine Nollet [b. Pimprez, France, November 19, 1700, d. Paris, April 12, 1770] constructs one of the first electrometers. It consists of a suspended pith ball, which moves in response to a body charged with static electricity.

William Watson tries to determine the velocity of electricity and incorrectly concludes that it is instantaneous.

I Tools

Benjamin Franklin describes in a letter his discovery that a pointed conductor can draw off electric charge from a charged body. This discovery is the basis for the lightning rod even before Franklin proves that lightning is a form of electricity. *See also* 1744 ENER; 1749 EAR.

1748

॥ Archaeology

Marcello Venuti publishes *A Description of the First Excavations at the Antique City of Herculaneum*, the world's first archaeological report. *See also* 1736 ARCH; 1763 ARCH.

* Astronomy

James Bradley announces his discovery of the nutation of

Earth's axis, a small periodic change in the precession of the equinoxes caused by the gravitational forces of the Sun and the Moon. *See also* 1749 AST.

☛ Biology

L'homme machine ("man the machine") by French physician Julien Offroy de la Mettrie [b. St. Malo, France, December 25, 1709, d. Berlin, November 11, 1751] depicts humans as machines without freedom or will.

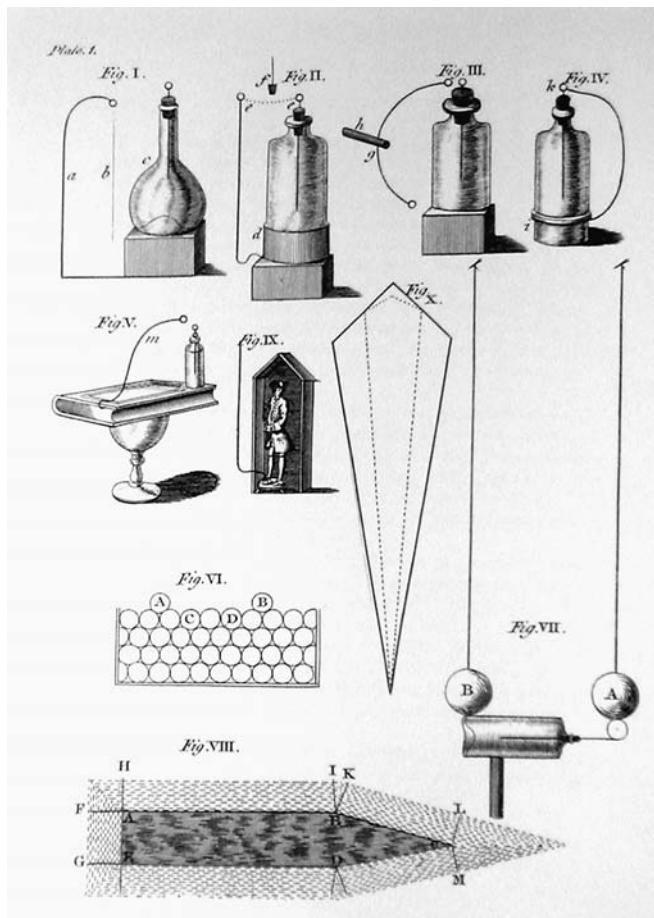
Naturalist John Needham [b. London, September 10, 1713, d. Brussels, Belgium, December 30, 1781] and Comte de Buffon conduct an experiment, famous at the time, that seems to prove spontaneous generation. Needham observes "little animals" that appear in boiled sealed flasks of broth. Later experiments show that spores of these creatures enter the broth between the time of boiling and sealing. *See also* 1768 BIO.

❖ Materials

John Wilkinson [b. Cumberland, England, c. 1728, d. July 14, 1808] establishes his iron works in Bilston, England, where after much experimentation he develops an improved blast furnace. *See also* 1340 MATR; 1776 TOOL.

Σ Mathematics

Euler's *Introductio in analysin infinitorum* ("introduction to infinitesimal analysis") popularizes the concept of function, first introduced by Leibniz, develops the analytic interpretation of the trigonometric functions, and sums various infinite series with abandon, if not great rigor.



FRANKLIN'S EXPERIMENTS AND OBSERVATIONS ON ELECTRICITY Benjamin Franklin's 1747 letter to Peter Collinson concerning the use of a pointed conductor to draw off an electric charge and subsequent letters on electricity were "corrected, methodized, improved, and now first collected into one Volume and illustrated with COPPER PLATES" in 1769. The main plate, shown here, depicts the key experiments. The bottom drawing (Fig. VIII) illustrates Franklin's idea of why an electric field would be concentrated near a sharp corner instead of at the blunt end.

Colin Maclaurin's posthumously published *A Treatise of Algebra* contains the method for solving systems of equations that is known as Cramer's rule, although the version by Gabriel Cramer [b. Geneva, Switzerland, July 3, 1704, d. Bagnoles, France, January 4, 1752] is not published until two years later. See also 1767 MATH.

♥ Medicine & health

John Fothergill [b. Car Eng, England, March 8, 1712, d. London, December 26, 1789] gives the first description of diphtheria in his *Account of the Putrid Sore Throat*.

✿ Physics

Mikhail Lomonosov formulates the laws of the conservation of mass and energy. See also 1782 CHEM.

Jean-Antoine Nollet discovers and explains osmotic pressure. See also 1885 CHEM.

William Watson observes "rays" of electricity in a tube. See also 1878 COMM.

I Tools

Pierre Le Roy [b. Paris, 1717, d. 1785] invents a clock in which an impulse is transmitted to the escapement only when the pendulum swings to one side but not when it swings to the other, making the escapement independent of the amplitude of the pendulum swing. See also 1765 TOOL.

English inventor Daniel Bourn develops a carding machine. See also 1789 TOOL.

1749

★ Astronomy

Alexis Clairaut discovers a common error in all approximate solutions of the three-body problem that attempt to explain the motion of the Moon in terms of Newton's theory of gravitation. He corrects the error and finds that the revised calculations accurately match the lunar orbit. See also 1747 AST; 1757 AST.

Jean le Rond D'Alembert's *Recherches sur la precession des équinoxes et sur la nutation de la terre* ("researches on the precession of the equinoxes and on the nutation of the Earth") gives the first mathematical explanation of the regular changes in the orientation of Earth's axis. See also 1748 AST; 1765 PHY.

✿ Biology

Comte de Buffon's *Histoire naturelle, générale et partic-*

ulière ("general and particular natural history") begins a 55-year, 44-volume account of all that is known about animals and minerals. Buffon gives the modern definition of a species, a group of organisms capable of breeding and producing fertile offspring. See also 1753 COMM.

Denis Diderot's *Lettre sur les aveugles* ("letter on the blind") describes his materialist ideas, the dependence of humans on their senses, and a discourse on his theory of variability and adaptation.

⊕ Earth science

Benjamin Franklin installs a lightning rod on his home in Philadelphia, mainly to test his theory that lighting is electricity that is attracted to sharp points. See also 1747 TOOL; 1752 PHY.

In *Protogaea*, published posthumously, Leibniz explains that Earth probably passed from a gaseous through a molten state to its present form. See also 1745 EAR.

♥ Medicine & health

Observations on Man by David Hartley [b. Yorkshire, England, August 30, 1705, d. Bath, England, August 28, 1757], the first work in English to use the term "psychology," is a systematic attempt to interpret the phenomena of mind by the theory of association; Hartley also argues that dreams might reinforce associative memories.

✿ Physics

Jean-Jacques d'Ortous de Mairan [b. Béziers, France, November 26, 1678, d. Paris, February 20, 1771] describes the Chinese refrigerator in *Dissertation sur la glace* ("dis-

Verifying Newton's theory of gravitation

When Newton formulated his theory of gravitation he had one competitor, Descartes, with his theory of vortices. Newton's theory called for a universal force of gravitation that interacts between all bodies throughout the universe. Descartes assumed that force cannot be transmitted through empty space and that a vortex of matter moves Earth around the Sun.

Descartes' theory predicted that Earth is flattened at the equator and elongated at the poles. A Newtonian Earth should be flattened at the poles and fatter at the equator. In 1718 Jacques Cassini published measurements of the curvature of Earth that he and his father, Jean-Dominique, had made. They found that the curvature of Earth was greater the closer one came to the North Pole, a result in agreement with Descartes' theory.

In 1733 Charles-Marie de la Condamine suggested an expedition to measure the curvature of Earth on the equator. La Condamine directed this expedition, which left France in 1736 and returned ten years later. Another Frenchman, Pierre Maupertuis, directed a similar expedition, to Lapland from 1736 to 1737. The measurements made by the two expeditions were compared, and it was shown convincingly that Earth is flattened at the poles and

oblate at the equator, a result consistent with Newton's theory. The Cassinis' measurements had been in error.

A second challenge to Newton's theory during the 18th century concerned the problem that the theory could not explain the motion of the Moon. To calculate the motion of the Moon, one has to take into account not only the attraction between the Moon and Earth, but also the force between the Moon and Sun. Determining motions under such a combination of forces is known as the three-body problem. Because it seemed impossible to solve the equations governing the motion of three bodies exactly, scientists, including Jean le Rond D'Alembert, Alexis Clairaut, and Leonhard Euler, developed methods for successive approximations to the solutions of these equations. All found that the calculated lunar apogee (the point in the Moon's orbit farthest from Earth) was totally different from the one observed. Clairaut, however, who strongly believed that Newton's theory was correct, found a common error in all these approximations, which he announced in 1749. Clairaut was then able to use Newtonian mechanics to calculate the observed position.

One of the most convincing proofs that Newton's theory of gravitation was correct came in 1759. Edmond Halley had predicted that the great comet of 1682 would return in 1758 or 1759. Clairaut, using more precise calculations, predicted the return of the comet for 1759, with a margin of error of only 30 days. Halley's comet turned up at the predicted time.

sertation on ice"), recognizing the cooling effect of evaporation. *See also* 1857 FOOD.

Writer Gabrielle Emilie la Tonnelier de Breteuil, marquise du Châtelet [b. Paris, December 17, 1706, d. Lunéville, France, September 10, 1749] completes the only translation of Newton's *Principia* ever made into French, done with the help of Alexis Clairaut, one of Madame du Châtelet's lovers. Voltaire, another of her lovers, also encouraged her in her work and wrote the preface for the first (1759) edition. *See also* 1729 PHY.

John Canton [b. Stroud, England, July 31, 1718, d. London, March 22, 1772] develops a method for making a strong artificial magnet. *See also* 1745 MATR; 1750 PHY.

→ Transportation

Philip Vaughan patents radial ball bearings for carriage axles. *See also* 1496 TOOL; 1862 TOOL.

1750

★ Astronomy

An Original Theory and New Hypothesis of the Universe by Thomas Wright [b. Byers Green, England, September 22, 1711, d. Byers Green, February 25, 1786] explains the Milky Way as a collection of stars confined between two parallel planes and proposes that the Sun and stars form a giant system rotating around a common center. *See also* 1761 AST.

Astronomer Nicolas Louis de Lacaille [b. Rumigny, France, May 15, 1713, d. Paris, March 21, 1762] makes the first exten-

sive catalog of 2000 southern stars at the Cape of Good Hope and also determines the angles of solar and lunar parallaxes. *See also* 1762 AST; 1881 AST.

↳ Communication

Leipzig bookseller Johann Heinrich Zedler [b. Breslaw (Wroclaw, Poland), 1706, d. Leipzig, (Germany), 1760] produces the 64-volume German encyclopedia *Universal Lexicon* — the first volume was published in 1732 — which is soon followed by a supplement of four volumes (1754). *See also* 1728 COMM; 1751 COMM.

❖ Materials

Although cast iron is slowly replacing wrought iron in Europe, it still amounts only to 5 percent of all iron used.

Σ Mathematics

Gabriel Cramer's *Introduction à l'analyse des lignes courbes algébriques* ("introduction to the analysis of algebraic curves") contains the famous Cramer's rule for solving systems of linear equations — actually discovered by Colin Maclaurin at least two years earlier.

⌘ Physics

A Treatise on Artificial Magnets by geologist John Michell [b. Nottinghamshire, England, 1724, d. Thornhill, England, April 21, 1793] reports his discovery of the inverse-square law for the attractive and repulsive forces of magnetism, now known as Coulomb's law from Coulomb's rediscovery about 30 years later. It also includes essentially the same method of making strong arti-

ficial magnets as discovered, but not published, by John Canton. *See also* 1749 PHY; 1785 PHY.

Pierre de Maupertuis' *Essai de cosmologie* ("essay on cosmology") claims that the Principle of Least Action proves the existence of God. *See also* 1744 PHY.

1751

Biology

Carolus Linnaeus's *Philosophia botanica* ("botanical philosophy") rejects any notion of evolution and continues his work in classifying plants. *See also* 1735 BIO; 1789 BIO.

Essay on the Vital and Other Involuntary Motions of Animals by Robert Whytt [b. Edinburgh, Scotland, September 6, 1714, d. Edinburgh, April 15, 1766] refutes Georg Stahl's doctrine that the soul causes involuntary motion in animals and argues that the irritability of living tissues is caused by a stimulus. Whytt is the first to describe reflex actions and conditioned responses, demonstrating, for example, that the contraction of the pupil in response to light is a reflex motion. *See also* 1752 MED.

Pierre de Maupertuis' *Système de la nature* is a theoretical speculation on heredity and the origin of species by chance. *See also* 1735 BIO; 1789 BIO.

Chemistry

Axel Fredrik Cronstedt [b. Turiinge, Sweden, December 23, 1722, d. Stockholm, Sweden, August 19, 1765] announces his discovery of nickel (Ni) to the Swedish Academy of Sciences.

Communication

Denis Diderot and Jean le Rond D'Alembert publish the first volume of their *Encyclopédie, ou dictionnaire raisonné des sciences, des art, et des métiers* ("encyclopedia, or rational dictionary of sciences, arts, and manners") on June 28. It will be complete in 17 volumes of articles and 11 of illustrations in 1772. *See also* 1747 COMM; 1765 COMM.

The Ecole Supérieure de Guerre ("high school of war") is founded in Paris. *See also* 1794 COMM.

Medicine & health

The first institution to treat mental patients is opened in London. *See also* 1764 MED.

Physics

Benjamin Franklin shows that electricity can magnetize and demagnetize iron needles. He describes electricity as a single fluid and distinguishes between positive and negative electricity in *Experiments and Observations on Electricity*. *See also* 1749 EAR; 1752 PHY.

1752

Astronomy

Great Britain and the American colonies adopt the Gregorian calendar by having September 14 directly follow September 3. January 1 becomes the beginning of the year instead of March 25, the former date. In England there are widespread protests demanding that the government "give us our eleven days back!" *See also* 1582 AST.

Johann Tobias Mayer [b. Marbach, Germany, February 17, 1723, d. Göttingen (Ger-

many), February 20, 1762] prepares tables of the motion of the Moon compared to the motion of the stars that are accurate enough for finding the longitude at sea to within half a degree. These are published posthumously in 1770, enabling his widow to obtain a £3000 prize from the British Board of Longitude for the method. *See also* 1714 TRAN; 1765 TOOL.

Biology

René de Réaumur discovers the role of gastric juices, showing that digestion is chemical and not merely mechanical. He feeds a hawk meat protected by a metal cylinder; upon recovery the meat is partially digested. He also uses stomach juice from the hawk to digest meat outside the body. *See also* 1822 MED.

Earth science

Nicolas Desmarest [b. Soulaines, France, September 16, 1725, d. Paris, September 28, 1815] proposes that England and France were once connected by a land bridge that has since been washed away by sea currents. *See also* 1785 EAR.

Mathematics

Euler states the theorem that in any simple convex polyhedron the sum of the vertices and the faces equals 2 plus the number of edges, commonly known as Euler's formula ($V - E + F = 2$), although the formula was discovered earlier by René Descartes.

Medicine & health

Albrecht von Haller [b. Berne, Switzerland, October 16, 1718, d. Berne, December 12, 1777]

writes in *De partibus corporis humani sensilibus et irritabilibus* ("a dissertation on the sensible and irritable parts of animals") that muscle tissue has the ability to contract when stimulated. *See also* 1757 MED.

Treatise on Midwifery by obstetrician William Smellie [b. Lanark, Scotland, 1697, d. Lanark, March 5, 1763] is the first scientific approach to obstetrics. *See also* 1774 MED.

Physics

In June, Benjamin Franklin performs his famous kite experiment — flying a kite in a thunderstorm, feeling a shock when the string is touched, and observing other familiar effects of static electricity. The kite experiment shows that lightning is a form of electricity, similar to the discharge from a Leiden jar. *See also* 1749 EAR; 1753 PHY.

Tools

Following suggestions from Benjamin Franklin and others, a 12-m (40-ft) iron rod is erected in a field at Marli near Paris, where it succeeds in attracting lightning. Soon afterward an early lightning rod is attached to a building in Paris. *See also* 1749 EAR; 1778 TOOL.

Newgate Prison in London is equipped with an air ventilation system powered by a windmill (called the "ventilator") and designed by the biologist, chemist, and inventor Stephen Hales.

1753

Biology

Carolus Linnaeus's *Species plantarum* ("forms of plant")

The French describe technology

During the 18th century, few books on technology appeared in England — progress in technology was the domain of the practitioner. In France, however, the savant was actively interested in technology, and there was a deluge of books on the topic.

As early as in 1675, Louis XIV instructed the French Académie des Sciences to create a treatise on all the machines used by artisans and manufacturers. Jacques Buot started work on this project, but died before he could accomplish anything. The project came in the hands of several committeees but remained essentially dormant until 1751, when the first volume of Denis Diderot's *Encyclopédie*, a competing project, was published. It greatly interested the French public.

The *Descriptions des arts et métiers, faites ou approuvées par Messieurs de l'Académie des Sciences avec figures* ("description of the arts and trades made or approved by the members of the Académie des Sciences, with illustrations") did not start actual publication until 1761. The first volume was *L'art du charbonnier* ("the art of the coal miner"). Etching of plates to illustrate the volumes, however, had been started very much earlier, around the end of the 17th century. Consequently, once actual publication started, the *Descriptions des arts et métiers* was complete in 20 volumes at an average rate of one a year, finishing in 1781.

The *Encyclopédie, ou dictionnaire raisonné des sciences, des art, et des métiers*, published by Diderot and Jean Le Rond D'Alembert, took twice as long to complete from first volume to supplement. But it was the *Encyclopédie* and not the *Descriptions* that became the most influential work of the Enlightenment, mainly because of the introduction of new ideas and views in the *Encyclopédie*, many opposing the existing order imposed by church and state. The authors shocked in other ways as well, as in Voltaire's learned article on fornication in Volume VII (1757).

By 1759 publication was stopped on orders of the government, but various means were found to proceed anyway. According to one story (attributed to Voltaire) the final permission to publish resulted from Madame de Pompadour remarking that she did not understand how her rouge or silk stockings were made. The duc de la Vallière said that the answers to her questions could be found in the outlawed *Encyclopédie*. When this truth had been demonstrated to Madame and to Louis XV, the king lifted the ban and publication was hurriedly completed before he could change his mind.

One of the aims of the *Encyclopédie* editors and authors, known as the *encyclopédistes*, was to give a complete picture of technology as it existed at the time. The *encyclopédistes* were convinced that technical knowledge had to be treated the same way as other forms of knowledge, thus making technology part of culture. In this Diderot defended the artisan, the manual worker, affirming that the expertise of the artisan is as valuable as that of the artist. The efforts of the *encyclopédistes* resulted in a very large collection of plates of machines and tools, and a large number of articles on the different arts and crafts, making the *Encyclopédie* the most complete source of information on the state of technology during the first half of the 18th century.

A large number of the articles were written by Diderot himself, including many on technology, describing manufacture of steel and bronze; agriculture and bread making; needles, shirts, and shoes, as well as Madame Pompadour's silk stockings; and the boring machine. Diderot did not rely only on existing descriptions of machines and techniques but observed how artisans used their machines. Then he tried to explain the construction and functioning of these machines as best he could, with mixed results. One of the most interesting articles is Diderot's one on the knitting machine for stockings, a moderately sophisticated machine invented in England by William Lee about 1589, which Diderot learned to operate himself. He also supervised the famous illustrations showing the textile industry, gunpowder production, and pin manufacture.

The main reason that Diderot wrote most of the articles treating with technology himself was that he could not find authors for these articles. The members of the Académie des Sciences were involved with their own project, the *Descriptions des arts et métiers*, and many of the practitioners of the different technologies were not skilled at explaining their own work. However, a number of engineers and scientists contributed articles and several artisans contributed articles on their craft: Contributions on clocks were written by two well-known watchmakers in Paris, J.B. Leroy and Ferdinand Berthoud.

The technology described in the *Encyclopédie* remained, however, traditional, not progressive. The editors aimed at showing the perfection of machines and crafts and included very little about developments that took place during the preparation of the encyclopedia. The topic of steam engines is hidden away in the article "Fire," and some of the articles, such as "Forging," describe methods that were already outdated.

completes his development of the use of binary nomenclature in botany and remains the foundation for the present-day classification of species. See also 1735 BIO.

Communication

In Scotland, Charles Morrison proposes in *Scots Magazine* the construction of a telegraph consisting of 26 electri-

cal lines, each corresponding to a letter of the alphabet; individual letters would be indicated by the movement of a light object repelled when a

current passes through one of the wires. See also 1774 COMM. Denis Diderot publishes *Pensées sur l'interprétation de la nature* ("thoughts on the

interpretation of nature”), a philosophical essay inspired by Comte de Buffon’s *Histoire naturelle*. See also 1749 BIO.

A supplement to Chambers’s *Cyclopaedia*, largely prepared by Ephraim Chambers before his death, but edited by botanist John Hill [b. c. 1714, d. 1775], is published. At seven volumes, the supplement is longer than either the first or second editions (1728 and 1738, respectively). See also 1728 COMM; 1788 COMM.

🍴 Food & agriculture

Zinnias and marigolds, both native to Mexico, are first imported into England. See also 1790 FOOD.

♥ Medicine & health

Treatise on Scurvy by James Lind [b. Edinburgh, Scotland, October 4, 1716, d. Hampshire, England, July 13, 1794] reports his controlled experiment that establishes the curative effect of oranges and lemons on scurvy. Lind thinks oranges work better than lemons. See also 1795 MED.

⌘ Physics

Dell’ elettricismo artificiale e naturale by Giovanni Battista Beccaria [b. Mondovi, (Italy), October 3, 1716, d. Turin, Italy, May 27, 1781] reports his experiments and generally supports Benjamin Franklin’s theories about electricity. See also 1751 PHY.

In Russia a Swedish experimenter, George Wilhelm Richmann, is killed performing a kite experiment similar to the one performed by Benjamin Franklin. See also 1752 PHY.

1754

★ Astronomy

Nicolas Louis de Lacaille compiles a catalog of 42 nebulae that includes 14 “nebulous star clusters” that will later be recognized as open clusters of stars in the Milky Way Galaxy. See also 1781 AST.

Optician John Dollond [b. London, June 10, 1706, d. London, November 30, 1761] invents the heliometer, a telescope that produces two images that can be manipulated to determine angular distances accurately, for finding the diameter of the Sun (its intended use) or the distances between stars. See also 1667 AST.

🔬 Biology

Traité de sensations (“treatise on sensations”) by Etienne Bonnet de Condillac [b. Grenoble, France, September 30, 1715, d. Beaugency, France, August 3, 1780] claims that knowledge reaches humans only through the senses. See also 1758 MED.

⌚ Communication

The *Discours préliminaire* to Diderot’s *Encyclopédie* becomes a cardinal document of the Enlightenment. See also 1751 COMM.

🌐 Earth science

The first volume of *Neue erdbeschreibung* (“new geography”) by Anton Friedrich Busching [b. Stadthagen, Germany, September 27, 1724, d. May 28, 1793] is published. By 1792 it will consist of 11 volumes, with 6 of them describing European geography. It lays the foundation for modern statistical geography.

🍴 Food & agriculture

Charles Bonnet’s *Recherches sur l’usage des feuilles des plantes* (“study of the use of plant leaves”) details the nutritional value of plants.

❖ Materials

The first iron-rolling mill is started at Fareham, Hampton, England. See also 1790 MATR.

♥ Medicine & health

The University of Halle (Germany) graduates the first female medical doctor.

✈ Transportation

Ferdinand Berthoud [b. Plancemont, Switzerland, March 19, 1727, d. Grosley, France, June 20, 1807] develops a rugged marine chronometer for routine shipboard use. See also 1759 TRAN.

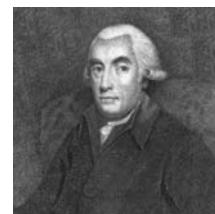
1755

★ Astronomy

Immanuel Kant [b. Königsberg, East Prussia (Kalinigrad, Russia), April 22, 1724, d. Königsberg, February 12, 1804] suggests in *Allgemeine Naturgeschichte und Theorie des Himmels* (“general natural history and theory of the heavens”) that the observed nebulae are large star systems like the Milky Way and that the solar system originated from a dust cloud. See also 1796 AST.

❖ Chemistry

Scottish chemist Joseph Black shows that carbonates are compounds of a base and of a gas that he terms “fixed air,” which we know today as carbon dioxide. See also 1764 CHEM.



Joseph Black

[b. Bordeaux, France, April 16, 1728, d. Edinburgh, Scotland, December 6, 1799]

Black’s contributions to chemistry and materials science were few, but fundamental. In his doctoral thesis he introduced quantitative methods to chemistry and showed that carbon dioxide, previously known only from respiration and fermentation, can be produced by heating calcium carbonate; it also will recombine with the resulting calcium oxide. His experiments detected carbon dioxide in air and showed that it forms an acid in water. Black’s other work is now part of thermodynamics. He discovered latent heat and also observed, but failed to understand, differences in specific heat between materials.

⌚ Communication

The University of Moscow is founded.

🏗 Construction

The second Eddystone Light, built in 1709 after the first was swept away in a storm, is destroyed in a fire; it had been 28 m (92 ft) tall and built of wood. See also 1709 CONS; 1759 CONS.

🌐 Earth science

An earthquake in the ocean near Lisbon, Portugal, kills more than 60,000 people and destroys the city. Lisbon is rebuilt, using a rectangular layout of streets. See also 1811 EAR.



Joseph-Louis Lagrange

[b. Turin (Italy), January 25, 1736, d. Paris, April 10, 1813]

Lagrange developed many general ideas for handling mathematical problems, such as the use of higher dimensional spaces to describe the motion of a body. He put the subject known as calculus of variations, a powerful tool for finding minimum or maximum functions, into its present form. Although his famous book without pictures is called *Méchanique analytique* ("analytical mechanics"), he was very much a pure mathematician, contributing, for example, to number theory. His main influence at a more familiar level comes from the metric system, whose foundation was in large part according to his plan.

1757

★ Astronomy

Alexis Clairaut obtains the best figures to date for the masses of the Moon and the planet Venus. See also 1749 AST.

♥ Medicine & health

Albrecht von Haller's *Elementa physiologiae corporis humani* is a survey of the physiological knowledge of the time; it details his research on the muscles and blood circulation of the human body. See also 1752 MED; 1759 MED.

❀ Physics

Mikhail Lomonosov's books *Theory of Electricity* and *Origin of Light and Color* include his advocacy for the wave theory of light. See also 1746 PHY; 1801 PHY.

Scotsman William Cullen [d. 1790] observes the cooling effect of evaporating liquids and publishes the results in *An Essay on the Cold Produced by Evaporating Fluids and Some Other Means of Producing Cold*. See also 1749 PHY; 1857 FOOD.

☒ Tools

John Wilkinson patents a hydraulic blowing machine that uses waterpower to drive a bellows.

Captain John Campbell [b. Kirkcudbrightshire, Scotland, c. 1720, d. London, December 16, 1790] improves the octant version of a sextant invented by John Hadley by extending the arc to a sixth part of a circle, creating the true sextant. See also 1731 TOOL.

Σ Mathematics

French mathematician Joseph-Louis Comte de Lagrange writes to Euler about his new foundation for the calculus of variations and the differential equation of minimal surfaces. See also 1744 MATH.

I Tools

French playwright Pierre-Augustin Caron de Beaumarchais [b. Paris, 1732, d. Paris, May 18, 1799] invents a clock that can be wound by turning a ring on the clock's face. Previous clocks had to be opened to get to a mechanism for rewinding. See also 1770 TOOL.

✈ Transportation

Liverpool, England, merchants finance the digging of the short Sankey Brook Canal, which joins the river Mersey to a coalfield. This is the earliest recorded transportation canal in England. See also 1666 TRAN; 1761 TRAN.

upon Magnesia, Quicklime, and Other Alkaline Substances is the first detailed examination of chemical action and the first work on quantitative chemistry.

❀ Earth science

A study of the rocks of the Harz Mountains and the Erzgebirge by Johann Gottlob Lehmann [b. Pirna, Saxony (Germany), August 4, 1719, d. St. Petersburg, Russia, January 22, 1767] is a pioneering work in local geology. Soon other geologists begin to study specific sites.

❖ Materials

The first cotton velvets are made at Bolton, Lancashire, England. See also 1845 MATR.

♥ Medicine & health

Philipp Pfaff [b. 1715, d. 1767] publishes *Abhandlung von den Zähnen*, giving the first

description of casting models to make false teeth. See also 1771 MED.

❀ Physics

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✈ Transportation

Charles Augustin Coulomb reinvents the diving bell. See also 1716 TRAN; 1759 CONS.

1756

★ Astronomy

John Canton makes the first observation of magnetic storms in Earth's magnetic field. See also 1766 EAR.

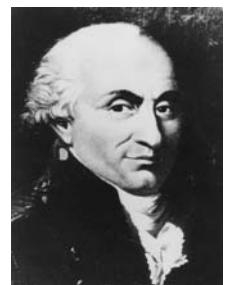
☒ Chemistry

Joseph Black's *Experiments*

Charles Augustin Coulomb

[b. Angoulême, France, June 14, 1736, d. Paris, August 23, 1806]

Although Coulomb is best remembered for his work with electric charges, he was also the first to show that the force of friction is always proportional to the pressure exerted at 90° to the surface. His experiments with electricity, using a sensitive apparatus called the torsion balance, showed that the force between two charges displays inverse variation with respect to the square of the distance between the charges and direct variation with respect to the product of their size (mathematically the same as the law of gravity).



1758

★ Astronomy

John Dollond and Chester Moor Hall [b. Leigh, Essex, England, December 9, 1703, d. Sutton, England, March 17, 1771] independently construct achromatic telescopes; that is, telescopes that avoid the defect of chromatic aberration, which Newton thought would be present in all lenses. Dollond's lens of flint glass and crown glass is presented to the Royal Society on June 8.

Charles Messier [b. Badonviller, France, June 26, 1730, d. Paris, April 11, 1817] rediscovers the Crab Nebula, now known to be the remnant of a supernova explosion in the constellation Taurus. It will become M1 in the Messier catalog of nebulae. *See also* 1731 AST; 1928 AST.

Johann Georg Palitzsch [b. Dresden, Saxony (Germany), June 11, 1723, d. February 21, 1788] locates Comet Halley on December 25; this is the first observation of a comet at a predicted return date. Alexis Clairaut had predicted earlier in the year that the comet would come closest to Earth within 30 days of April 1759; its closest approach is actually in March 1759. *See also* 1705 AST; 1804 AST.

☛ Biology

Duhamel du Monceau's *La physique des arbres* ("the physics of trees") describes the structure and physiology of trees.

☚ Chemistry

Theoriam philosophiae naturalis redacta ad unicam legem virium in natural existentium ("a theory of natural philosophy

John Smeaton

[b. Leeds, England, June 8, 1724, d. Aushorpe, England, October 28, 1792]

Smeaton gave up law to become a mathematical instrument maker. He investigated windmills and water wheels and pioneered the application of cast iron in machinery. He is regarded as the father of civil engineering in Britain. Among his chief works are the redesign and construction of Eddystone Lighthouse, several substantial bridges, and the Forth and Clyde canal.



reduced to a single law of the actions existing in nature") by Jesuit mathematician Roger Joseph Boscovich (a.k.a. Ruggero Giuseppe Boscovich) [b. Ragusa, Dalmatia (Dubrovnik, Yugoslavia), May 18, 1711, d. Milan (Italy), 1787] introduces a form of atomic theory based on atoms as pointlike structures that are attracted to each other by a force that varies with distance. Essentially, this is the same idea as a field in physics, and Boscovich's concept influences Michael Faraday to introduce the field concept. An enlarged third edition will be published in 1763. *See also* 50 BCE PHY; 1845 PHY.

Axel Fredrik Cronstedt's *Essay on the New Mineralogy* distinguishes four classes of minerals: earths, bitumens, salts, and metals, and begins the classification of minerals by chemical structure as well as appearance. *See also* 1745 EAR; 1774 EAR.

☛ Communication

A commission in England sets standards, known as the Imperial Standards, for measures of length, capacity, weight, and so forth. *See also* 1790 COMM.

☛ Medicine & health

De l'esprit (in English also

called *Essays on the Mind*), by philosopher Claude Adrien Helvetius [b. Paris, January 26, 1715, d. Paris, December 26, 1771], endorses the idea that the mind develops as a result of the sensations it perceives, rather than as a result of inborn tendencies. The book is publicly burned in Paris and condemned by the English Parliament. *See also* 1754 BIO; 1829 MED.

☛ Tools

Jedediah Strutt [b. Derbyshire, England, July 28, 1726, d. Derby, May 7, 1797] invents the ribbing machine for the manufacture of stockings. *See also* 1589 TOOL; 1816 TOOL.

1759

☛ Biology

Theoria generationes ("theory of generation") by physiologist Kaspar Friederich Wolff [b. Berlin (Germany), January 18, 1734, d. St. Petersburg, Russia, February 22, 1794] claims the existence of a *vis essentialis* (essential force) that is at the basis of living matter. Wolff also describes the differentiation of tissues in a developing embryo, refuting the concept of miniature creatures in sperm. *See also* 1768 BIO.

☛ Construction

John Smeaton in October builds the first successful version of the Eddystone Lighthouse. His techniques, such as using mortar that sets under water (as the Romans did) and using Coulomb's diving bell, are copied in most lighthouses built subsequently. The light itself still consists of tall candles. Smeaton's building lasts until it is replaced by a higher structure after more than 100 years' use. *See also* 1755 CONS; 1877 CONS.

Engineer James Brindley [b. Thornsett, England, 1716, d. Turnhurst, England, September 30, 1772] builds the first canal that crosses a river on a fixed aqueduct. The canal passes over the river Iswell in England instead of lowering to the level of the river with locks and then raising again. *See also* 1755 TRAN; 1761 TRAN.

☛ Energy

John Smeaton presents the Royal Society with the results of his research on the performance of windmills in *Experimental Inquiry Concerning the Natural Power of Water and Wind to Turn Mills and Other Machines Depending on a Circular Motion*. Using models, Smeaton determines the optimum blade size, shape, twist, number of revolutions per

minute (rpm), ratio of tip speed to wind speed, and so on, all of which are still fundamental to wind turbine design. He concludes that windmills cannot compete with the more powerful steam engines of his time. *See also* 1854 ENER.

♥ Medicine & health

Albrecht von Haller's *Experimenta physiologiae corporis humani* ("physiological experiments of the human body"), in nine volumes, published from 1759 to 1766, is a general overview of physiology. *See also* 1757 MED.

✿ Physics

Tentamen theoriae electricitatis et magnetismi ("examination of a theory of electricity and magnetism") by Franz Ulrich Theodore Aepinus [b. Rostock (Germany), December 13, 1724, d. Tartu, (Estonia), August 10, 1802] suggests that in the absence of electricity, ordinary matter repels itself. This idea supports Benjamin Franklin's one-fluid theory of electricity. *See also* 1751 PHY; 1760 PHY.

✈ Transportation

John Harrison completes Number Four, the marine chronometer that will eventually win the British Board of Longitude's prize for a practical way to find the longitude at sea. *See also* 1735 TRAN.

1760

★ Astronomy

Photometria by Johann Heinrich Lambert, [b. Mulhausen (Germany) August 26, 1728, d. Berlin, September 25, 1777] is an investigation of light reflec-

tions from planets, introducing the term *albedo* "whiteness" for the differing reflectivity of planetary bodies.

✿ Biology

Vorläufige Nachricht von Einingen das Geschlecht der Pflanzen Betreffende Versuche und Beobachtungen ("preliminary report on experiments and observations of certain species of plants") by Joseph Gottlieb Kölreuter [b. 1733, d. 1806] describes the author's research on heredity in plants. *See also* 1857 BIO.

The Botanical Gardens in Kew, London, opens. *See also* 1639 BIO.

☛ Communication

Cabinetmaker Konrad Faber in Nuremberg (Germany) starts the commercial production of pencils. *See also* 1795 COMM.

✿ Earth science

John Michell's "Essay on the Causes and Phenomena of Earthquakes" proposes that earthquakes are waves produced when one layer of rock rubs against another; however, Michell proposes that this is caused by a volcano's turning water into steam. He also notes that such waves could be used to locate where an earthquake originates. *See also* 1705 EAR.

Mikhail Lomonosov explains the formation of icebergs.

Giovanni Arduino [b. Capriano, (Italy), October 16, 1714, d. March 21, 1795] subdivides geologic time. His category Tertiary is eventually adopted by Charles Lyell. *See also* 1830 EAR.

Σ Mathematics

Euler uses his phi (ϕ) function to show that if two numbers are relatively prime, then one of them exactly divides (with no remainder) the difference found by subtracting 1 from the second number raised to the value of the phi function of the first. Recently, this theorem has become central to modern cryptography as the basis of the "public-key" codes. *See also* 1977 MATH.

✿ Physics

In experiments with primitive apparatuses, Daniel Bernoulli decides that the electric force obeys an inverse-square law similar to that of gravity. *See also* 1749 PHY; 1785 PHY.

I Tools

Jacques de Vaucanson builds a metal lathe mounted on an iron bed in an iron frame, forming a very rigid structure. This lathe is the precursor of machine tools that will be developed during the 19th century. *See also* 1741 TOOL.

1761

★ Astronomy

Joseph Nicolas Delisle organizes a worldwide effort to observe the transit of Venus, which can be used to calculate solar parallax and the distance from Earth to the Sun, an idea proposed by Jeremiah Horrocks and made popular by Edmond Halley. *See also* 1676 AST; 1768 EAR.

Mikhail Lomonosov discovers the atmosphere of Venus while observing a transit of Venus across the Sun.

Johann Lambert's *Cosmologische Briefe* ("cosmological let-

ters") contains a theory for the structure of the Milky Way in which stars are contained in giant spherical clusters that are confined to a region of small thickness. *See also* 1750 AST.

Nicolas Louis de Lacaille makes an accurate measurement of the distance of the Moon, taking into account that Earth is not a perfect sphere. *See also* 150 BCE AST.

✿ Biology

De la nature (five volumes) by Jean Baptiste Robinet [b. 1735, d. 1820] claims that organic species form a linear scale of progress without gaps. *See also* 1735 BIO; 1789 BIO.

Joseph Kölreuter begins publishing his experiments showing that wind and insects promote pollination in plants and on plant fertilization. *See also* 1793 BIO.

The first veterinary school is founded at Lyon, France.

☛ Communication

Originally started in 1675 by Jacques Buot, publication begins on *Descriptions des arts et métiers, faits ou approuvées par Messieurs de l'Académie des Sciences avec figures* ("description of the arts and trades made or approved by the members of the Academy of Sciences, with illustrations"), a huge compilation in 76 volumes on technology. The project is completed in 1789.

Σ Mathematics

German minister Johann Peter Süssmilch [b. 1707, d. 1767] initiates the study of population statistics. *See also* 1662 MATH.

The taming of the longitude

The Phoenicians were the world's first great navigators. They determined the location of their ships in terms of the length and width of the Mediterranean, the sea on which they sailed. The Phoenicians taught their navigational methods to the Greeks, from whom the Romans learned. Eventually translated into Latin, the sailors' two perpendicular directions became the longitude (*longus*, or long) and latitude (*latus*, or wide). Eratosthenes drew a map of the known world around the third century BCE that included lines of latitude and longitude, but his lines were determined by large cities; that is, they were not equally spaced. In the second century BCE Hipparchus of Nicaea greatly improved on this by spacing the lines equally around the globe. By assigning 360° to the circumference of Earth, and by using Eratosthenes' nearly correct calculation for the size of Earth, Hipparchus was able to obtain good distances for a degree. Hipparchus's system continues in use today.

Sailors of classical times, however, used only half the system — the latitude. Early travelers observed the changes in the constellations as one travels north or south. One star, Polaris, is visible every clear night in the Northern Hemisphere, but its position dips closer to the horizon as one travels south. At the North Pole, Polaris is directly overhead; it disappears below the horizon at the equator. Until sailors began to travel in the Southern Hemisphere, all that was needed to find the latitude was an instrument for measuring how high Polaris, the pole star, was above the horizon. The Portuguese sailors who rounded the Cape of Good Hope were terrified because they had lost their main navigational tool on the trip down the side of Africa.

Sailors did not use the longitude because they had no way to measure it. The historian of Magellan's circumnavigation reported that Magellan himself spent long hours trying to find ways to measure the longitude, but those under him were too proud of their navigational skills to speak of it. Common sailors and their pilots believed that they could navigate by a combination of charts, dead reckoning, and the latitude. Governments, however, realized that this was not good enough. The governmental view was particularly brought home to the English when in 1691 and again in 1707 large parts of the British navy were lost because of navigational errors.

Much earlier, in 1598, Philip III of Spain offered the first of several prizes by seagoing nations for the person who could find the longitude. Among the schemes suggested to Philip was one from Galileo. Having discovered the four largest satellites of Jupiter, he proposed that they could be used to locate the longitude. Galileo's idea was based using charts that showed the relative positions of the satellites at different times. By observing the positions, one can determine the time. From the time, one can find the latitude. By telling the time exactly, one can determine the longitude.

As a clock is carried from place to place, it will be off by one hour for each 15° of longitude. This is why there are four time zones in the lower 48 states of the United States. This part of the United States is approximately 4×15 or 60° of longitude wide. Comparing universal time with local time helps one to obtain the longitude. Local noon can be obtained easily by determining when the Sun reaches its daily zenith. It is universal time that is hard to obtain.

For example, if you get a long-distance phone call while you are in New York City and you do not know where the call is from, you can ask "What time is it?" If it is noon in New York, and the caller says 11 a.m., then you know the caller's longitude is approximately between 90° W and 107° W, the approximate longitude of Central time in the United States.

To determine the exact longitude, however, you need to forget about time zones and compare Sun times between two places. Specifically, compare local Sun time with Universal Time (UT), formerly known as Greenwich Mean Time (GMT), the time at longitude 0°. If you know it is 1:00 p.m. UT and you observe the sun time where you are to be noon, your longitude is exactly in 15° W.

Astronomical events that repeat frequently are a good way to obtain Universal Time. Eclipses of the Moon could be used, for example, if they were not too infrequent to be of much use to sailors. The positions of Jupiter's moons are more useful because one or another is frequently eclipsed. Although Galileo's suggestion was ignored by Philip, it was taken up in the 17th century by French astronomers, led by Giovanni Cassini. Using Jupiter's moons, the French were able to establish correctly the longitude of cities in Europe and of islands in the Atlantic. The observations required, however, were too difficult and too time-consuming to be done by sailors at sea.

In 1530, Gemini Frisius suggested that the easy way to solve the problem would be to carry a good clock, set to some universal time, with the ship. Others had the same idea but clocks of the time were inadequate for the degree of precision needed. Even after Huygens developed a pendulum clock that theoretically kept good time, it was too imprecise to find the longitude and too delicate to be used on ships.

Christopher Columbus noted on his first voyage that the compass needle changed its deviation from true north as he sailed across the Atlantic. Many expeditions were launched in the 18th century — notably that of Edmond Halley — to chart these magnetic deviations in the hopes that they would lead to the secret of the longitude. It was discovered, however, that the deviations vary in such an unpredictable manner that they are unsuitable for this purpose.

In 1714, the English Parliament provided a reward of £20,000 for anyone who could find the longitude and demonstrate the method on a voyage to the West Indies. Many of the leading scientists of the eighteenth century worked on the problem in competition for the prize, but the achievement was accomplished by

a self-taught watchmaker, John Harrison. His clock Number Four — or marine chronometer, as it came to be called — made the West Indies trip in 1761 and passed the test with flying colors. All along the way Harrison's son, who was in charge of the chronometer, predicted landfalls with greater accuracy by far than the ship's pilots. Unfortunately for Harrison, the board gov-

erning the prize included a number of scientists who still hoped to get the money themselves. The board gave him half the prize after four years, and then stalled him again for seven more years. They would probably have stalled longer if King George III had not intervened on Harrison's behalf and obtained the remainder of the prize for him.

♥ Medicine & health

Leopold Auenbrugger [b. Graz, Austria, November 19, 1722, d. Vienna, Austria, May 18, 1809] uses his musical knowledge to develop the technique of percussion for diagnosis of chest disorders. He publishes his findings in *Inventum novum*. See also 1826 MED.

Giovanni Morgagni writes *De sedibus et causis morborum per anatomen indagatis* ("on the seats and causes of diseases, investigated by anatomy"), which establishes that many diseases are located in specific organs. It is the first important work in pathological anatomy. See also 1706 MED; 1774 MED.

⌘ Physics

Joseph Black discovers that ice, when melting, absorbs an amount of heat without changing in temperature, a phenomenon termed latent heat. Later he measures the latent heat of steam — that is, the heat

required to keep water boiling without raising its temperature. See also 1739 PHY; 1772 PHY.

I Tools

With John Harrison's marine chronometer Number Four aboard and his son William Harrison to take the readings, the HMS *Deptford* sails off toward the West Indies to test whether Harrison's method can be used to find the longitude at sea. See also 1759 TRAN; 1765 TOOL.

✈ Transportation

The Bridgewater Canal designed by James Brindley and built by the Duke of Bridgewater to carry coal from mines in Worsley to Manchester opens on July 17. It is the first English canal to include an aqueduct portion in which the canal crosses over a river, the Irwell at Barton. The canal passes 12 m (39 ft) above the river. See also 1755 TRAN; 1773 TRAN.

1762

▲ Archaeology

James Stuart [b. England, 1713, d. 1788] and Nicholas Revett [b. England, 1720, d. 1804] publish *The Antiquities of Athens Measured and Delinated*, a detailed set of drawings of all the buildings and decorations of the Acropolis of Athens. See also 1764 ARCH.

★ Astronomy

James Bradley completes a new star catalog that contains the measured positions of 60,000 stars. See also 1750 AST; 1798 AST.

◊ Materials

John Roebuck converts cast iron into malleable iron by action of pit fire and artificial blast at the Carron Ironworks in Stirlingshire, Scotland. See also 1754 MATR; 1784 MATR.

I Tools

Samuel Klingenstierna [b. Linköping, Sweden, August 18, 1697, d. Stockholm, October 26, 1765] wins the prize of the Russian Academy of Science for the best method of constructing optical instruments free of chromatic aberration. See also 1830 TOOL.

1763

▲ Archaeology

Workers digging a canal near the base of Mount Vesuvius discover the lost city of Pompeii, buried along with Herculaneum in the eruption of Mount Vesuvius of 79 CE. See also 1748 ARCH.

⊕ Earth science

Antoine-Laurent Lavoisier helps the geologist Jean-Étienne Guettard with a mineralogical atlas of France. See also 1746 EAR; 1770 EAR.

Antoine-Laurent Lavoisier

[b. Paris, August 26, 1743, d. Paris, May 8, 1794]

Lavoisier used careful measurement and thoughtful experiments to turn chemistry into a science. He also explained the experiments of others, such as Joseph Priestley's discovery of oxygen and Henry Cavendish's production of water from hydrogen and oxygen. Lavoisier used the results of other chemists and his own experiments to create the modern theory of fire and to explain the role of air in combustion and respiration. He was among the first to have a clear concept of a chemical element and the first to list the known elements. He also developed the idea of naming compounds from elements. In addition, Lavoisier was the first to use and to state clearly a conservation law for mass. For these reasons, he is known as the father of modern chemistry.



Jeremiah Dixon [b. Durham, England, July 27, 1733, d. Durham, 1771] and Charles Mason [b. England, 1730, d. Philadelphia, Pennsylvania, 1787] begin their survey of the Pennsylvania-Maryland boundary that will end five years later with the Mason-Dixon line.

Energy

Ivan Polzunov [b. 1729, d. 1766] designs a double-cylinder atmospheric steam engine that supplies rotary motion. The machine is completed in 1766, driving bellows at the Kolivano-Voskresensky silver mine at Barnaul, where it works for a few months; it then breaks down. Because Polzunov has died, there is nobody that can repair the machine. *See also* 1732 ENER; 1781 ENER.

Food & agriculture

There are indications that ground tobacco leaves are used in France to control aphids. *See also* 1800 FOOD.

Materials

Josiah Wedgwood [b. Staffordshire, England, July 12, 1730, d. Staffordshire, January 3, 1795] patents the cream-colored earthenware that becomes the standard domestic pottery of England. *See also* 1782 MATR.

Mathematics

Gaspard Monge [b. Beaune, France, May 10, 1746, d. Paris, July 28, 1818] develops descriptive geometry, consisting of methods used to show three-dimensional figures on a plane. The technique remains a French military secret until 1795. *See also* 1799 MATH.



WEDGWOOD'S JASPER WARE PORTLAND VASE Although the ceramic material known as stoneware is not so hard or translucent as porcelain, English potters were able to create some of the world's best vases and tableware with it. In 1777 Josiah Wedgwood invented a hard, unglazed stoneware that could be made in brilliant colors, which he named jasper ware after a resemblance to the semiprecious stone jasper. Starting in 1790 and continuing to today, the Wedgwood factory has made these jasper ware imitations of a famous Roman glass vase from the first century CE.

Medicine & health

The first American medical society is founded in New London, Connecticut.

Tools

Joseph Oxley patents the use of a ratchet mechanism for creating rotary motion from a reciprocating steam engine; the system is not very efficient and is not commonly used. *See also* 1842 TOOL.

William Hutchinson [b. Newcastle, England, 1715, d. Feb-

ruary 11, 1801] fits out a lighthouse in Liverpool with bowl-shaped reflectors of tin and glass mirrors in sizes as large as 3.65 m (12 ft) in diameter.

Transportation

The British Mariner's Guide by astronomer Nevil Maskelyne [b. London, October 6, 1732, d. Greenwich, England, February 9, 1811] is a practical guide to methods of navigation. *See also* 1767 AST.

Archaeology

Johann J. Winckelmann [b. (Germany) 1717, d. Trieste (Italy) June 8, 1768] publishes *Geschichte der Kunst des Alterthums* ("history of ancient art"), which provides the first systematic treatment of Greek and Roman sculpture, vases, and other artifacts.

Astronomy

Charles Messier starts the creation of his catalog of nebulous celestial objects, which contains 40 objects in its first version, with the aim to facilitate the search for planets. *See also* 1758 AST; 1769 AST.

Joseph-Louis Lagrange's *Libration de la lune* ("libration of the Moon") explains the librations of the Moon; that is, the periodic oscillation of the Moon from side to side that permits us to see somewhat more than half the lunar surface. It wins a prize from the Académie des Sciences. *See also* 1747 AST.

Biology

Dictionnaire raisonné universel d'histoire naturelle ("universal dictionary of natural history") by Jacques Christophe Valmont de Bonnare [b. Rouen, France, 1731, d. 1807] is published in several editions until 1791. It provides an organizational structure that will influence most later dictionaries of natural history or science.

Charles Bonnet's *Contemplation de la nature* ("contemplation of nature") gives his theory of preformation. He believes that each creature is already preformed in miniature in the egg, and that this tiny creature

contains an egg with its descendant preformed within it, and so on ad infinitum.

Chemistry

Irish physician David MacBride publishes *Experimental Essays*, in which he relates his discovery that van Helmont's gas sylvestre is identical to "fixed air" (now known as carbon dioxide). *See also* 1755 CHEM.

Communication

Pierre Fournier's *Manuel typographique* ("typographic handbook") is the first book on engraving and type founding. *See also* 1737 COMM.

Construction

French engineer Pierre Trésaguet [b. 1716, d. 1796] develops a base for highways that is made of a low arch perpendicular to the direction of travel built from flat stones set vertically. The plan is later adopted by Thomas Telford

[b. Dumfries, Scotland, August 9, 1737, d. London, September 2, 1834] and becomes known as a Telford base.

Earth science

John Lorimer [b. 1732, d. 1795] invents the dipping-needle compass, which shows magnetic inclination as well as north and south. He has one prototype made (probably the only one ever made) by Jeremiah Sisson, but also describes his invention in his 1795 book *A Concise Essay on Magnetism*.

Medicine & health

Robert Whytt publishes *Observations on Nervous, Hypochondriacal, or Hysterical Diseases*, one of the first important textbooks on neurology. *See also* 1751 MED; 1840 MED.

Tools

James Hargreaves [b. Blackburn, England, 1720, d. Nottingham, England, April 22, 1778] introduces the spinning jenny, patented in 1770. His first model is able to spin eight threads at once, although later models will

reach 120 threads. The thread produced is especially suited for wefts. *See also* 1738 TOOL; 1769 TOOL.

1765

Astronomy

John Winthrop's *Account of Some Fiery Meteors* includes calculations for the mass of comets. *See also* 1779 AST.

Chemistry

Karl Wilhelm Scheele discovers prussic acid.



Karl Wilhelm Scheele

[b. Stralsund (Germany), December 19, 1742, d. Köping, Sweden, May 21, 1786]

Scheele discovered chlorine in 1774 but failed to recognize it as an element. He discovered oxygen in 1771, but publication was delayed. Thus English chemists are credited with both discoveries. But Scheele indisputably was the first to compound ten of the most familiar acids, including tartaric, oxalic, and lactic acids, as well as the three gases hydrogen fluoride, hydrogen sulfide, and hydrogen cyanide. He was also the first to recognize the effect of light on silver compounds, the basis of photography.

The Lunar Society

Shortly after the arrival in Birmingham, England, of physicist and teacher William Small in 1764 from Virginia (where he had been one of Thomas Jefferson's most influential teachers), the Lunar Circle was founded. Small carried a letter of introduction from Benjamin Franklin to Franklin's friend Matthew Boulton. Boulton, Small, and physician and poet Erasmus Darwin became the founding members of the society. In 1775 the group reorganized more formally as the Lunar Society.

The Lunar Society occupies a special place in the history of the Industrial Revolution. It included physician John Roebuck, who, with another member, Samuel Garbett, founded the first sulfuric acid factory; James Watt, the inventor of many improvements on the steam engine; Joseph Priestley, one of the great chemists of the period; Josiah Wedgwood, the potter who made various advances in ceramics; William Withering, who introduced digitalis as a treatment for heart disease; William Murdoch, who

developed coal gas for lighting; John Wilkinson, who developed superior machinery for boring cylinders; and Benjamin Franklin, a corresponding member.

The Lunar Society received its name from its practice of holding its monthly meetings on the Monday night nearest the full Moon so that members would have an easy time seeing their way home. The members, of course, were called Lunatics.

Interactions between the members of the society aided the development of both science and industry. For example, Boulton ran a water-powered mill that needed more power. He thought that a Newcomen steam engine could pump water from below the water wheel to above it, increasing the flow. James Watt, who was already working on improvements in the steam engine, visited Birmingham and was introduced to Boulton, who bought a share of Watt's patents. Boulton then formed the Boulton & Watt firm to make steam engines, greatly improved by the excellent cylinders bored by Lunatic John Wilkinson.

Communication

The final volume of Denis Diderot's *Encyclopédie* is published, although the illustrations will not be complete for another seven years. *See also* 1751 COMM; 1772 COMM.

The fifth edition of Voltaire's *Dictionnaire philosophique* ("philosophical dictionary") argues against the Great Chain of Being, a concept that orders inanimate matter, plants, and animals into a hierarchy. *See also* 1664 COMM.

Matthew Boulton [b. Birmingham, England, September 3, 1728, d. Birmingham, August 18, 1809] founds the Lunar Circle, an institution to promote the arts and sciences, having James Watt, Joseph Priestley, and Erasmus Darwin among its members. The name comes from the practice of scheduling sessions so members can return home by moonlight after meetings.

Energy

James Watt builds a model of a steam engine in which the condenser is separated from the cylinder so that the cylinder does not lose heat each time the steam condenses, resulting in a power source six times as effective as the Newcomen engine. The first such engines in full scale will be

installed in 1776. *See also* 1712 ENER; 1769 ENER.

John Smeaton starts experimenting with a small atmospheric steam engine. *See also* 1774 TOOL.

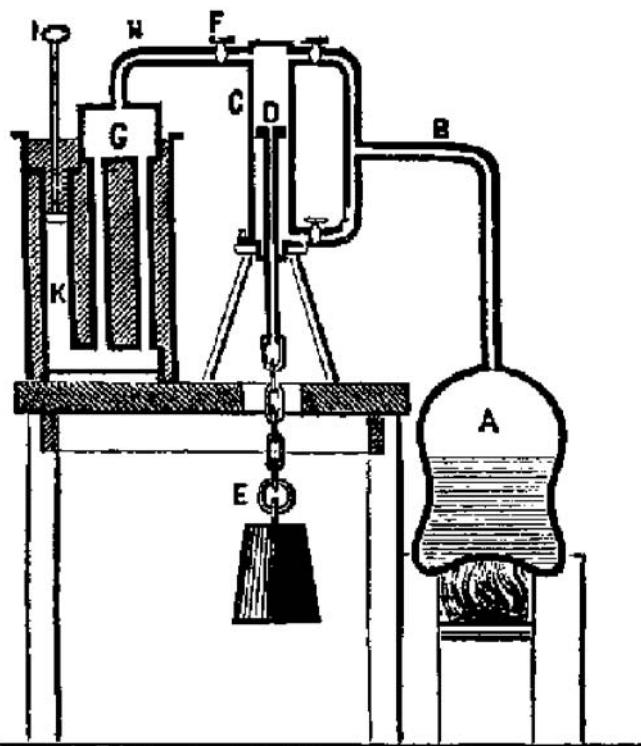
William Brown builds a steam engine fed with four steam boilers. Three boilers supply steam while the fourth is kept as a spare. It is the first example of intentional redundancy in technology known. *See also* 1776 ENER.

Food & agriculture

Lazzaro Spallanzani suggests preserving food by sealing it in containers that do not permit air to penetrate. *See also* 1795 FOOD.

Materials

Rails made from cast iron are used in English mines. *See also* 1754 MATR.

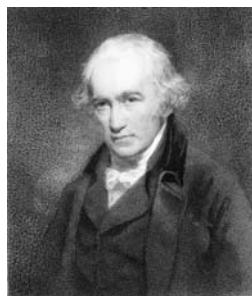


THE ORIGINAL MODEL WATT STEAM ENGINE After repairing the model Newcomen engine, Watt began to think of improvements. One Sunday the whole idea came together in his head as he was out walking, and on Monday he built a simple model, using a few pieces of pipe and a brass surgeon's syringe for a piston. The model, sketched here, was easily able to lift a weight of 18 pounds. Watt then began to plan for a full-sized engine.

Lazzaro Spallanzani

[b. Scandiano, (Italy), January 12, 1729, d. Pavia (Italy), February 11, 1799]

Spallanzani conducted important experiments in many areas. Working with microorganisms, he helped discredit the theory of spontaneous generation. He also showed that boiling water is a better sterilizing agent than hot air, and that some microorganisms can live for days in a vacuum. Spallanzani studied plant and animal reproduction and carried out experiments on the artificial insemination of frogs.



James Watt

[b. Greenock, Scotland, January 19, 1736, d. Heathfield, England, August 19, 1819]

In 1764, while repairing a steam engine designed by Thomas Newcomen, Watt saw a way to improve its efficiency significantly. The Newcomen engine wasted a lot of steam; Watt realized that this could be avoided by having a condensation chamber separate from, but connected to, the cylinder, thereby allowing the cylinder to remain hot. Watt built and successfully tested a small model of his engine. The first two steam engines with his new design were installed in 1776. Later he developed a method for producing rotary motion from the reciprocating action of the original, making the steam engine suitable for powering ships and locomotives. He also adapted a feedback device called a governor to the steam engine; this automatically keeps the engine from running too fast. Demand for Watt's engines was high, and they played an important role in the Industrial Revolution.

The atmospheric steam engine

Thomas Newcomen and Thomas Savery both thought of using steam to pump water from mines in 1698, the year that Savery applied for his patent for the Miner's Friend.

Water, limiting the depth of mines in Britain, was then a major problem. With pumping water as the aim, steam engines of the first half of the 18th century did not provide rotary motion at all. Steam in a Savery or a Newcomen engine is at the same pressure as the atmosphere and then cooled to produce a partial vacuum that raises a piston in a cylinder. Such engines are termed "atmospheric."

For 60 years, many atmospheric engines were built that did not differ greatly from Newcomen's design, which was more efficient than Savery's. The versatile engineer John Smeaton, known for his scientific approach to practical engineering problems, started systematically investigating a number of Newcomen engines in England. In 1765 Smeaton built an experimental

model engine near his home. He also studied in detail 15 of the approximately 100 existing atmospheric engines in England, and so determined the optimal proportions for atmospheric engines of different sizes. In addition, he improved the execution of engine parts, especially the piston and cylinder, and succeeded in doubling the performance of his engines.

Around 1760 engineers became interested in using steam engines for hauling coal from deep mines, and Smeaton completed in 1777 his "water coal-gin." An atmospheric engine pumped water into an elevated cistern that supplied water to an overshot water wheel that could run in both directions. The same idea, using a steam pump to power a water wheel, had been introduced a decade earlier. But it was the improvements in the Newcomen engine made by James Watt, who not only created machines that supplied rotary motion, but also increased vastly their performance, that made the steam engine the driving force of the Industrial Revolution. The first two of the Watt engines were already at work when Smeaton's water coal-gin was built.

♥ Medicine & health

John Morgan [b. Philadelphia, Pennsylvania, June 10, 1735, d. Philadelphia, October 15, 1789] founds the first medical school in America at the College of Pennsylvania.

⌘ Physics

Euler gives a general treatment of the motion of rigid bodies, including the precession and nutation of Earth in *Theoria motus corporum solidorum seu rigidorum* ("theory of the motion of solid and rigid bodies"). See also 1748 AST.

I Tools

John Harrison receives the first half the prize offered by the British Board of Longitude by building a chronometer accurate within one-tenth of a second per day and demonstrating that it could be used to find the longitude accurately on a voyage to the West Indies. See also 1761 TOOL; 1772 TOOL.

Thomas Mudge [b. Exeter,

Henry Cavendish

[b. Nice, France, October 10, 1731, d. London, February 24, 1810]

A wealthy recluse, Cavendish worked on scientific problems for his entire long life. He was the first to show that water is a compound and that air is a mixture — previously both were thought to be elements. In the process he discovered hydrogen and developed methods for weighing and measuring gases. But he is best known for his experiment determining the gravitational constant G. This experiment is often called "weighing the Earth," since knowing G permits one to calculate Earth's mass. Cavendish used Earth's mass to find its density, which is greater than that of stone, implying a heavy core. He also made advances in the study of heat and electricity; but these results were not published until long after his death and after their independent discovery by others.



England, 1715, d. 1794] develops the detached-lever (free-anchor) escapement for balance-wheel clocks, an improvement over the cylinder escapement invented by George Graham because the friction between the anchor and gear is reduced. This type of escapement continues in general use. See also 1748 TOOL.

1766

★ Astronomy

Johann Daniell Titius [b. Konitz, (Germany), January 2,

1729, d. Wittenberg, (Germany), December 16, 1796] proposes that the distances of the planets to the Sun are proportional to the terms of the series 3, 6, 12, 24, 48, 96. This law is later published by Johann Elert Bode [b. Hamburg, (Germany), January 19, 1747, d. Berlin, November 23, 1826] and is commonly known as Bode's law. The discovery of Neptune 70 years later will disprove the law. See also 1772 AST.

▷ Chemistry

On Factitious Airs by English chemist Henry Cavendish

announces his discovery of hydrogen, which he terms "inflammable air." See also 1670 CHEM.

Dictionnaire de chymie by Pierre-Joseph Macquer [b. Paris, October 9, 1718, d. February 15, 1784] is the first chemical dictionary organized on modern systematic lines.

⊕ Earth science

Navigator Louis-Antoine Bougainville [b. Paris, November 11, 1729, d. Paris, August 31, 1811] begins his journey around the world, visiting

Tahiti, Samoa, and the New Hebrides. *See also* 1771 EAR.

Giant bones, parts of a creature later named *Mosasaur* (Meuse lizard), are found near the Meuse River in the Netherlands. Workers in the stone quarry where the bones are found do not know what they are, however. They are identified as giant marine reptiles after the skull is found in 1780. *See also* 1780 EAR.

German physicist Johan Carl Wilcke [b. Mecklenburg, (Germany), September 6, 1732, d. Stockholm, Sweden, April 18, 1796] sets up the first chart of magnetic inclination. *See also* 1756 AST; 1828 EAR.

Σ Mathematics

Joseph-Louis Lagrange is summoned to Berlin by Frederick the Great, since, as Frederick put it, “it is necessary that the greatest geometer of Europe should live near the greatest of kings.” Lagrange stays in Berlin for 20 years, completing most of his best work there.

Theoried der Parallellinien (“theory of parallel lines”) by Johann Lambert is an attempt to prove Euclid’s Fifth, or Parallel, Postulate by the indirect method; that is, from the assumption that it does not hold, to find a contradiction. Lambert develops much of what we recognize as non-Euclidean geometry, finding no contradictions. *See also* 1733 MATH; 1781 MATH.

I Tools

Horace-Bénédict de Saussure [b. Geneva, Switzerland, February 17, 1740, d. Geneva, January 22, 1799] invents the electrometer, a device for measuring the electric poten-

tial by means of the attraction or repulsion of charged bodies. *See also* 1786 TOOL.

✈ Transportation

On July 26 the 224.6-km-long (139.5-mi-long) Grand Trunk Canal officially opens. Designed by James Brindley and John Smeaton, it joins the Bridgewater Canal to the river Severn. *See also* 1761 TRAN; 1777 TRAN.

1767

★ Astronomy

Nevil Maskelyne begins publication of an annual book that shows the position of heavenly bodies at specific times — known as an ephemeris. It is called *The British Nautical Almanac and Astronomical Ephemeris for the Meridian of the Royal Observatory at Greenwich*, but known simply as the *Nautical Almanac*. *See also* 1763 TRAN; 1802 TRAN.

▷ Chemistry

The History and Present State of Electricity by Joseph Priestley includes his explanation of the rings formed by an electric discharge on a metal (the rings are later named Priestley Rings). The book also suggests that electrical forces follow an inverse-square law (known today as Coulomb’s law), as

gravitational forces do. Priestley had been induced into writing this book after meeting Benjamin Franklin in London, and the book contains the only detailed account of the famous kite experiment. *See also* 1760 PHY; 1785 PHY.

↗ Energy

John Stewart (or perhaps Robert Rainey) is the first to use a steam engine directly, without the intermediary of water wheels, to power machinery. Earlier uses of steam to power machinery had used the engine as a pump to raise water, powering a conventional water wheel when the water flowed back into a reservoir. *See also* 1789 ENER.

Σ Mathematics

Euler’s *Vollständige Anleitung zur Algebra* (“complete instruction in algebra”), one of the first books Euler dictated after his blindness, shapes elementary algebra in the form that it retains to this day. *See also* 1748 MATH; 1770 MATH.

♥ Medicine & health

Physician George Baker [b. Devonshire, England, 1722, d. 1809] observes that an epidemic in Devonshire, recognized as early as 1703, is similar to lead poisoning that affects painters. Benjamin

Franklin tells Baker that in Massachusetts lead still heads have been banned because of the belief that lead in the rum causes “dry belly ache and the loss of the use of . . . limbs.” Baker determines that lead-lined cider presses, only used in Devonshire, are the cause of paralysis, stomach aches, and other symptoms. *See also* 1917 MED.

1768

↗ Biology

Lazzaro Spallanzani, in a series of experiments that begin in 1767, helps disprove John Needham’s theory of spontaneous generation. He observes that organisms might have entered Needham’s boiled broth before it was sealed from the air. In his experiment, the broth is boiled for more than 30 minutes in a flask that is already sealed; no “little animals” appear. His *Prodromo d’une ouvrage sur les reproductions animales* (“outline for a work on animal generation”) describes his demonstrations. *See also* 1748 BIO.

Kaspar Wolff’s *De formatione intestinarum* (“on the formation of the intestine”) establishes principles of the formation of organs in embryos. *See also* 1759 BIO; 1817 BIO.



Joseph Priestley

[b. Fieldhead, England, March 13, 1733, d. Northumberland, Pennsylvania, February 6, 1804]

Priestley was a brilliant teacher and Unitarian minister who learned theories of electricity from Benjamin Franklin. Although Priestley was an amateur scientist, his experiments with electricity and later with gases contributed enormously to the field of chemistry. Before Priestley the only known gases were air, carbon dioxide, and hydrogen, but Priestley discovered ten more, most notably oxygen.

Communication

Publication of *Encyclopaedia Britannica* starts in weekly issues. *See also* 1765 COMM; 1771 COMM.

Earth science

English navigator James Cook [b. Marton, England, October 27, 1728, d. Kealakekua Bay, Hawaii, February 14, 1779] begins the first of his three voyages to the Pacific; he observes the transit of Venus in Tahiti and explores the coastline of New Zealand. *See also* 1761 AST; 1769 AST.

Energy

Jesse Ramsden [b. Halifax, England, October 15, 1735, d. Brighton, England, November

5, 1800] invents an electrostatic generator that can be used to charge Leiden jars. The mechanism involves turning a large glass disk with a crank, which then uses friction to generate charge. The Ramsden generator is used to treat paralysis, muscle spasms, and heart problems with electric shocks.

Mathematics

Johann Lambert proves that π is an irrational number. Thus, when π is expressed as an infinite decimal, it will not repeat any pattern; nor can π be exactly equal to the ratio of two natural numbers. *See also* 1717 MATH.

Euler's *Institutiones calculi*

integralis, published in three volumes between 1768 and 1770, is a textbook on the integral calculus that also contains many of Euler's own discoveries about differential equations. *See also* 1767 MATH; 1780 MATH.

Medicine & health

Robert Whytt's *Observations on the Dropsey of the Brain*, published posthumously, gives the first description of tuberculous meningitis in children.

Tools

Antoine Baumé [b. Senlis, France, February 26, 1728, d. Paris, October 15, 1804] invents the graduated hydrometer, using the scale now known as the Baumé

scale for specific gravities of liquids. *See also* 1824 TOOL.

1769

Astronomy

Observations of the transit of Venus are made from stations all over the world, including Tahiti (the expedition commanded by James Cook), the Russian-Chinese border (the expedition commanded by naturalist Pierre Simon Pallas [b. Berlin, September 22, 1741, d. Berlin, September 8, 1811], and Cavan, Ireland (by Charles Mason and colleagues). Astronomers will be able to use the data to establish size of the solar system. *See also* 1768 EAR.

The transit of Venus

Since orbits of the planets in the solar system are in virtually the same plane, Mercury and Venus can be seen as dots passing in front of the Sun. Such an event is a transit. Kepler was the first to recognize that transits must exist and to calculate when they would occur. With Kepler's calculations in hand, Pierre Gassendi was able to observe the transit of Mercury in 1631, a year after Kepler's death.

Transits of Venus have been especially important in the history of science. They occur in pairs, eight years apart, at intervals of 105.5 or 121.5 years. They can occur only near June or December — for example, the transits of Venus on June 8, 2004, and June 6, 2012. Jeremiah Horrocks improved on Kepler's calculations and became the first to observe a transit of Venus, on November 24, 1639. It was Horrocks who realized that if a transit of Venus were observed simultaneously from several places on Earth, the information gained could be used to calculate the distance to Venus and the distance from Earth to the Sun.

The first effort to accomplish this goal was organized by Joseph-Nicolas Delisle in 1761. Astronomers were dispatched to India, St. Helena, and other good viewing spots. War prevented some of the necessary observations from being made, and clouds

prevented others. A few observations were made, however. It was during this transit that astronomers discovered that Venus has an atmosphere.

The June 3, 1769, transit of Venus became the most famous. It was to observe this transit from Tahiti that Captain James Cook undertook the first of his great voyages of discovery. Leaving England on the *Endeavor* on August 26, 1768, Cook made the necessary observations in Tahiti and returned to England on July 17, 1771.

Cook's was not the only trip of discovery based on the 1769 transit. The Russians journeyed overland to Siberia to observe the event. Other observers were at various points around the globe.

In the mid-19th century, Johann Encke used the 1769 transit data to calculate Earth's distance to the Sun as 153,000,000 km (95,300,000 mi), the best calculation to that time.

For the transits of 1874 and 1882, George Airy organized vast expeditions to obtain data that could be used to improve on Encke's calculations. He failed, however, to recognize that the atmosphere of Venus causes enough error in the observations that no improvement can be made by this method. Later astronomers were able to arrive at more precise measurements by using the transits of asteroids, which have no atmosphere.

生物学

Charles Bonnet's *Philosophical Palingenesis, Or Ideas on the Past and Future States of Living Beings* contains his view that the females of every species contain the germ of all the future generations. *See also* 1759 BIO.

Denis Diderot's *La rêve d'Alembert* deals with such thorny questions as the ultimate constitution of matter and the meaning of life.

通信

The American Philosophical Society Held at Philadelphia for Promoting Useful Knowledge, first proposed by Benjamin Franklin in 1743, becomes the first American society for advancing science. *See also* 1660 COMM.

能源

James Watt is granted a patent for "a new method of lessening the consumption of steam and fuel in fire engines" embodied by his separate condenser steam engine. Instead of creating a vacuum inside the cylinder by condensing steam with a spray of water, the steam is condensed in a separate vessel. The process results in a considerable saving of fuel because the steam cylinder remains hot. *See also* 1765 ENER; 1775 ENER.

数学

Euler's *Dioptrica* (three volumes, 1769–71) lays the foundation for the calculation of the effects of optical systems.

物理学

John Robison [b. Glasgow, Scotland, 1739, d. January 1805] measures the repulsion between two charged bodies and shows that this force is

inversely proportional to the distance between the two bodies. *See also* 1760 PHY; 1785 PHY.

工具

Richard Arkwright receives a patent for a device that comes to be known as the hydraulic, or water-frame, spinning machine. It is especially good for spinning warps. As the water frame is too large and expensive to use in cottages, its invention leads to one of the key changes in Britain's Industrial Revolution, the introduction of centralized factories instead of decentralized cottage industry. *See also* 1764 TOOL; 1771 TOOL.

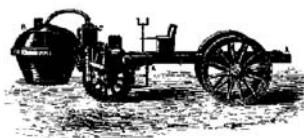
交通运输

Nicholas-Joseph Cugnot [b. Poid, France, September 25, 1725, d. Paris, October 2, 1804], a military engineer, builds a steam carriage that can carry four people at speeds up to 3.6 km per hour (2.25 mph), the first true automobile. *See also* 1670 TRAN; 1784 TRAN.

1770

天文学

Swedish astronomer Anders Johan Lexell [b. Åbo, Sweden, December 24, 1740, d. St.



Cugnot's Second Steam Carriage

The success of his first steam carriage encouraged Nicholas-Joseph Cugnot to build in 1770 a version for the army to use for transporting artillery, shown here. Although the carriage worked, it was hard to steer despite using power steering on the single wheel, which turned like the front wheel on a child's tricycle but with the aid of small steam engines. The boiler was also too small to power the large cylinders that would move the heavy wagon. The project was abandoned for lack of political support in the army, and Cugnot switched to designing and building railroad locomotives.

Petersburg, Russia, December 11, 1784] is the first to observe a short-period comet, but Jupiter's gravity flings the comet into space before it can return.

生物学

Johann Gottlieb Gahn [b. Voxna, Sweden, August 19, 1745, d. Falun, Kopparburg, Sweden, December 8, 1818] and Karl Wilhelm Scheele discover that phosphorus is an essential component of bones. *See also* 1669 CHEM; 1773 BIO.

化学

Karl Wilhelm Scheele discovers tartaric acid. *See also* 1765 CHEM.

地球科学

James Bruce [b. Stirlingshire, Scotland, 1730, d. April 27, 1794] discovers Lake Tana in the area of the sources of the Blue Nile.

Jean-Etienne Guettard publishes the first 16 maps of a proposed geological survey of France, which because of the revolution did not progress further. In the margins of the maps are drawings showing the vertical sequences of rock strata, an idea suggested by Guettard's assistant, Antoine-Laurent Lavoisier, who is better known today for his contributions to chemistry. *See also* 1746 EAR; 1778 EAR.

数学

Euler's *Einleitung zur Algebra* ("introduction to algebra") treats determinate and indeterminate algebra. It also contains his proof the Fermat's "last theorem" (that $x^n + y^n = z^n$ cannot be true for nonzero integers if n is greater than 2) is true for $n = 3$. *See also* 1676 MATH; 1825 MATH.



Richard Arkwright

[b. Preston, England, December 23, 1732, d. Derbyshire, England, August 3, 1792]

In the early 1760s weaving cotton cloth was a growing industry in England. Factories were unknown. Spinning cotton fibers into thread, then weaving the thread into cloth, was done by people in their homes. Arkwright heard about efforts to invent machines that could speed up the process and undertook his own experiments. He invented a spinning machine that spun fibers into strong threads of any desired thickness. Since it was too large to be operated by hand, Arkwright built a mill powered by horses and then a larger mill driven by water-power. The machine became known as the water frame. (In 1785 he switched to steam power.) As a result of moving the manufacture of cloth out of homes and into mills, Arkwright has been called the father of the factory system.

Meditationes algebraicae by Edward Waring [b. Shropshire, England, 1738, d. Shropshire, August 15, 1798] states without proof that every natural number is the sum of at most 9 cubes, 19 fourth powers, “and so on.” Although this conjecture is widely believed to be true, it will not be proved except for fourth powers, which will be established some 216 years after Waring’s conjecture. *See also* 1986 MATH.

I Tools

Swiss horologist Abraham-Louis Perrelet [b. Le Locle, Switzerland, January 9, 1729, d. 1829] constructs a watch with automatic winding. *See also* 1755 TOOL.

Jacques de Vaucanson develops the first Western chain drive, which is used in silk reeling and throwing mills. This is about 800 years after the development of the chain drive in China. *See also* 976 TOOL; 1869 TRAN.

→ Transportation

Richard Edgeworth, in Ireland, invents the tracked vehicle, actually a vehicle using individual segmented wheels instead of the more familiar tread around a pair of wheels. *See also* 1825 TRAN.

1771

★ Astronomy

Charles Messier publishes a catalog containing 45 nebulous objects, the first of his lists of objects that he wishes to identify so that they will not be mistaken for comets, which, like the objects in his list, have a smudged or fuzzy appearance. *See also* 1769 AST; 1781 AST.

Luigi Galvani

[b. Bologna, (Italy) September 9, 1737, d. Bologna, December 4, 1798]

While studying movement in frogs, Galvani discovered that muscles of a frog’s severed leg contract when in contact with two dissimilar metals because electric current is produced. Galvani incorrectly believed that the frog’s tissues generated the electricity and the metals discharged it. In 1800 Alessandro Volta showed that electricity is produced from the contact of two different metals in a moist environment. By analogy with the frog’s twitch, a person is said to be *galvanized* by any stimulus that causes a strong reaction.



◊ Chemistry

British chemist Peter Woulfe prepares picric acid, which is used principally as a yellow dye for a hundred years before it is realized that the substance is also highly explosive. *See also* 1770 CHEM.

⌚ Communication

The Smeatonian Club for engineers, named after John Smeaton, is founded in London. *See also* 1747 COMM; 1828 COMM.

The first bound edition of the *Encyclopaedia Britannica* is published in three volumes; editing has been variously attributed to William Smellie [b. Edinburgh, Scotland, 1740, d. Edinburgh, June 24, 1795], printer Colin MacFarquhar [b. Edinburgh, 1745, d. 1793], and engraver Andrew Bell [b. 1726, d. May 10, 1809]. *See also* 1768 COMM; 1796 COMM.

⊕ Earth science

Louis-Antoine Bougainville’s *Voyage autour du monde* (“voyage around the world”) recounts his journey of 1766–69 and argues that Earth has undergone great physical changes in the past. *See also* 1766 EAR.

♥ Medicine & health

The Natural History of the Human Teeth by John Hunter

[b. East Kilbridge, Scotland, February 13, 1728, d. London, October 16, 1793] lays the foundations of dental anatomy and pathology. *See also* 1530 MED; 1790 MED.

❀ Physics

Luigi Galvani discovers accidentally the action of electricity on the muscles of a dissected frog — a twitch. About 1780, while experimenting with this effect, he learns that certain metals can cause the same effect. He will publish his results in 1791. *See also* 1791 PHY.

Henry Cavendish’s work on electrical force leads to his mathematical single-fluid theory of electricity. This work anticipates many of the advances of the 19th century, but will not be published until after Maxwell’s theory, so it has no influence on the development of thinking about electricity. *See also* 1873 PHY.

I Tools

Richard Arkwright becomes the founder of the modern factory system when he builds a cotton spinning factory at Cromford in rural Derbyshire, England, that uses his water frame as its principal machine. The Cromford factory operates continuously

with hundreds of workers on shifts. *See also* 1769 TOOL.

Swiss watchmaker Ferdinand Berthoud publishes his *Traité des horloges marines* (“treatise on navigational clocks”). *See also* 1735 TRAN.

1772

★ Astronomy

A “law” proposed by Johann Titius that the distances of the planets to the Sun are proportional to the terms of the series that begins with 3 and doubles each term is publicized by Johann Elert Bode. It becomes known as the Titius-Bode law or, commonly, Bode’s law. *See also* 1766 AST; 1800 AST.

Joseph-Louis Lagrange calculates that each orbit contains five stable points, now called Lagrangian points, in which a body of smaller mass than the orbiting body can travel. *See also* 1995 AST.

◊ Chemistry

Lavoisier begins his experiments on combustion, proving that diamond can be burned and that the ash is carbon dioxide. He uses a large lens to focus the Sun’s rays on the diamond to burn it. He also establishes that when sulfur or phosphorus burns, its

gain in weight is due to its combination with atmospheric air. *See also* 1774 CHEM.

Karl Wilhelm Scheele discovers oxygen, which he calls “fire air,” but the discovery is not published until 1777, after Priestley’s publication of his independent discovery of oxygen in 1774. *See also* 1774 CHEM.

Priestley’s *Directions for Impregnating Water with Fixed Air* gives instructions for making seltzer water from carbon dioxide and water.

Digressions académiques (“academic digressions”) by Baron Louis Bernard Guyton de Morveau [b. Dijon, France, January 4, 1737, d. Paris, January 2, 1816], published by the French Academy, contains the first demonstration that metals gain weight on calcination (the chemical change that occurs when some metals are heated below the melting point). *See also* 1774 CHEM.

Priestley discovers that the volume of air decreases when an electric spark passes through it, but he does not determine why this happens. *See also* 1774 CHEM.

Daniel Rutherford [b. Edinburgh, Scotland, November 3, 1749, d. Edinburgh, November 15, 1819], Joseph Priestley, Karl Wilhelm Scheele, and Henry Cavendish all discover nitrogen (N) independently, with Rutherford generally credited as the first discoverer.

Communication

Euler’s *Lettres à une princesse d’Allemagne* (“letters to a German princess”), addressed to the niece of Frederick the Great, deals with mechanics, optics, acoustics, and astrono-

my at a popular level. The book is successful with the general public, being translated into seven languages.

The *Encyclopédie* of Denis Diderot and collaborators is completed in 17 volumes of text, finished in 1765, and 11 volumes of illustrations; a 5-volume supplement is issued between 1776 and 1780. *See also* 1771 COMM.

Construction

Jean-Rodolphe Perronet [b. Suresnes, France, October 25, 1708, d. Paris, February 27, 1794], director of the Ecole des Pont et Chaussées (“school of bridges and highways”), builds the Pont de Neuilly of the Seine below Paris. It is later (1827) copied by Thomas Telford in a bridge over the river Severn at Clouster, England. *See also* 1825 CONS.

Earth science

James Cook’s voyage (1772–75) to the South Pacific proves the nonexistence of any large southern continent by mapping the previously unexplored coasts of Australia. Since Antiquity scholars had incorrectly believed that the Southern Hemisphere contains a continent the size of Eurasia. *See also* 20 CE EAR; 1820 EAR.

Denis Diderot’s *Supplément aux voyages de Bougainville* (“supplement to Bougainville’s voyages”) hints at the possibility of continental drift. *See also* 1771 EAR; 1912 EAR.

Nevil Maskelyne suggests to the Royal Society an experiment for measuring Earth’s density. *See also* 1774 EAR.

Energy

John Smeaton builds an atmospheric steam engine that is two to three times more efficient than the Newcomen engines because of better machined cylinder walls. This results in a better seal between piston and cylinder walls. *See also* 1712 ENER.

Medicine & health

Anatomist Antonio Scarpa [b. Motta, (Italy), June 13, 1747, d. Bonasco, Italy, October 31, 1832] discovers the labyrinth of the ear; that is, the semicircular canals, vestibule, and cochlea.

Physics

Johan Carl Wilcke calculates the latent heat of ice (the amount of heat absorbed when ice turns into water). *See also* 1761 PHY.

Essai de cristallographie (“essay on crystallography”) by Jean Romé de Lisle [b. 1736, d. 1790] describes the process of crystallization and identifies 110 crystal forms.

Tools

French captain Nicholas Marion du Fresne and his crew are the second European group to land on Tasmania. They encounter and kill several Tasmanians. As Tasmania is settled, starting in 1803, the Europeans learn that Tasmanians have only stone and simple wood tools that are not ground or hafted, no domestic animals, no bone tools, no sewn clothing, no spear throwers, and no boomerangs.

Tasmanians do not fish or eat fish even though they live on an island. Although this lack of technology makes it appear that Tasmanians colonized the island before the Neolithic

Revolution, archaeological evidence shows that Tasmanians had abandoned bone technology and fishing about 3500 years BP. *See also* 1886 ANTH.

King George III of England has to intervene to get the British Board of Longitude to give John Harrison the second half of the prize money he won for devising the marine chronometer. *See also* 1765 TOOL.

1773

Astronomy

William Herschel studies the proper motion of 13 stars and deduces that the Sun moves toward the constellation Hercules. *See also* 1718 AST.

Mathematician and astronomer Pierre-Simon Laplace contributes a paper to the French Academy of Science in which he proves the stability of the solar system; that is, if a planet is perturbed by another planet, its average distance from the Sun cannot change much in millenniums.

Biology

Otto Friedrich Müller [b. Copenhagen, Denmark, March 2, 1730, d. Copenhagen, December 26, 1784] about this time becomes among the first to see bacteria since Leeuwenhoek and the first to classify them into types (*bacillus* and *spirillum*). *See also* 1683 BIO; 1872 BIO.

Hilaire-Marin Rouelle [d. April 7, 1779] investigates the compounds in vertebrate blood, finding sodium carbonate, potassium chloride, and sodium chloride. *See also* 1770 BIO.



William Herschel

[b. Hanover, (Germany) November 15, 1738, d. Slough, Buckinghamshire, England, August 25, 1822]

Herschel gained lasting fame as the first person to discover a new planet in the solar system, Uranus. He later discovered and named Titania and Oberon, satellites of Uranus. Additionally, he discovered two of Saturn's moons. But Herschel's primary interest was in stellar astronomy and nebulae. After studying thousands of previously undiscovered nebulae, he wrote that the Milky Way is a great collection of stars and that the nebulae are similar vast collections seen from a great distance. He retreated somewhat from this correct claim after studying planetary nebulae, which are true clouds of gas and not galaxies of stars. Herschel also made one major discovery outside of astronomy. While studying the temperature of sunlight he found infrared radiation, the first known invisible electromagnetic radiation.

Chemistry

Priestley's *Observations on Different Kinds of Air* reports that growing plants can restore air that has been made "lifeless" by animals or by fire (we now recognize that plants produce oxygen as a byproduct of photosynthesis). Priestley also notes that dew forms when hydrogen burns in oxygen; that is, water is a byproduct of hydrogen combustion. Eventually, this series of observations reaches three volumes, with the last published in 1777. See also 1777 CHEM.

Antoine Baumé's *Chimie expérimentale et raisonnée* ("experimental and theoretical chemistry") distinguishes between eight different affinities (forces between constituents of chemical compounds). See also 1718 CHEM.

Construction

Military engineer and scientist Charles Augustin Coulomb publishes *Essais sur une application des règles de maximis et minimis à quelques problèmes de statique relatifs à l'architecture* ("essay on an application of the rules of maxima and minima to some static problems in architecture"), the foundation of structural analysis for building construc-

tion. It deals with the laws of equilibrium, resolution of forces, friction, cohesion, and the behavior of beams under different kinds of loads. See also 1729 CONS.

Mathematics

Gotthold Ephraim Lessing discovers a Greek manuscript, generally attributed to Archimedes, that poses the following problem:

"The Sun god had a herd of cattle consisting of bulls and cows, one part of which was white, a second black, a third spotted, and a fourth brown. Among the bulls, the number of white ones was one half plus one third the number of the black greater than the brown; the number of the black, one quarter plus one fifth the number of the spotted greater than the brown;

the number of the spotted, one sixth plus one seventh the number of the white greater than the brown. Among the cows, the number of white ones was one third plus one quarter of the total black cattle; the number of the black, one quarter plus one fifth the total of the spotted cattle; the number of the spotted, one fifth plus one sixth the total of the brown cattle; the number of the brown, one sixth plus one seventh the total of the white cattle. What was the composition of the herd?" This becomes known as Archimedes' Cattle of the Sun. The solution will not be found until 1965. See also 1880 MATH.

Medicine & health

Lazzaro Spallanzani discovers the digestive action of saliva. See also 1752 BIO; 1822 MED.

I Tools

Jesse Ramsden invents the circular dividing engine, which accurately inscribes divisions onto scales. It becomes important in creating better navigational instruments for the British navy. See also 1768 ENER.

Transportation

The Bridgewater Canal designed by James Brindley, which opened in 1761, is finally completed with construction of the last locks. See also 1761 TRAN; 1777 TRAN.

1774

Biology

Exposition d'un nouvel ordre de plants adopté dans les démonstrations du Jardin Royal ("account of a new order of plants adopted during the exhibitions at the Royal Garden") by botanist Antoine Laurent de Jussieu [b. Lyon, France, April 12, 1748, d. Paris, September 17, 1836] proposes the taxonomic classification based on combining characteristics from all parts of a plant, not just the reproductive organs (as had been done by Linnaeus). See also 1753 BIO.

Pierre-Simon Laplace

[b. Beaumont-en-Auge, France, March 28, 1749, d. Paris, March 5, 1827]

Laplace used mathematics to study the origin and stability of the solar system, completing Newton's work in his book *Méchanique céleste* ("celestial mechanics"). In the process Laplace invented the general concept of potential as it applies to any field, such as a gravitational or electric field. Laplace was also the main contributor to probability theory before the 20th century.



Chemistry

Johann Gottlieb Gahn discovers the chemical element manganese (Mn).

Karl Wilhelm Scheele discovers chlorine, manganese, and barium, but for some reason is not assigned the credit for any of them. For example, Scheele does not recognize that chlorine is an element, which is noted by Sir Humphry Davy about 25 years later. He also discovers formic acid. *See also* 1770 CHEM; 1776 CHEM.

Priestley independently discovers oxygen (O) two years after Karl Wilhelm Scheele, but is the first to publish his results. *See also* 1772 CHEM; 1777 CHEM.

Priestley heats calx of mercury and finds that it turns into mercury without the presence of charcoal while producing nitrous oxide ("phlogisticated nitrous air" or "laughing gas"). *See also* 1800 CHEM.

Lavoisier's *Opuscules physiques et chymiques* gives the results of his experiments with combustion, showing that the calx of a metal gains weight by absorbing something from the air during combustion. *See also* 1772 CHEM.

Henry Cavendish repeats Priestley's observation of sparks through air and concludes correctly that the cause of the decrease in volume noted by Priestley is the formation of nitric oxides. When electric power becomes less expensive, this "spark method" becomes a major way to manufacture nitrogen compounds. The "spark method" is the principal natural way that nitrogen compounds are formed in nature, where they serve as important

plant fertilizers. *See also* 1772 CHEM; 1859 MATR.

Communication

George Louis Lesage [b. Geneva, Switzerland, June 13, 1724, d. Geneva, November 9, 1803] builds an electric telegraph with 26 electrical lines, one for each letter of the alphabet, following the design of Scottish inventor Charles Morrison. *See also* 1753 COMM; 1796 COMM.

Computers

German clergyman Philipp Matthäus Hahn builds a calculating machine that performs calculations with a precision of 12 digits; the machine is commercially successful and is manufactured until 1820. *See also* 1694 COMP; 1820 COMP.

Earth science

Von den ausserlichen Kennzeichen der Fossilien ("on the exterior characteristics of fossils") by German geologist Abraham Gottlob Werner [b. Wehrau, (Germany), September 25, 1750, d. Dresden, (Germany), June 30, 1817] introduces a method of classifying minerals by their physical characteristics, such as color, geometrical form, luster, transparency, and hardness. *See also* 1758 CHEM.

Nevil Maskelyne measures the mass of Earth by first determining the mass of the mountain of Schiehallion by how far it causes a plumb line to deviate from the horizontal. He concludes that Earth is 4.5 times as dense as water. *See also* 1772 EAR; 1798 PHY.

Medicine & health

Franz Mesmer [b. Baden, (Germany), May 23, 1734, d.

Meersburg, (Germany), March 5, 1815] develops his theory of "animal magnetism" — which comes to be called mesmerism and later is called hypnosis. Mesmer uses hypnotism to aid in curing disease. He also suggests that animal magnetism causes attraction between certain persons. *See also* 1841 MED.

Anatomy of the Human Gravid Uterus by William Hunter [b. Lanarkshire, Scotland, May 23, 1718, d. London, March 30, 1783] is Hunter's greatest work in anatomy. It contains 24 masterpieces of anatomical illustration. *See also* 1752 MED.

Tools

John Wilkinson patents a precision boring mill. The machine contains a rigid bar that leads the boring head through the cylinder instead of being self-centering, as earlier boring mills had been. This arrangement results in a high degree of precision. Initially developed for boring cannons, by this date the machine is turned to its new main purpose of producing cylinders for James Watt's steam engines, which would not function unless good tolerances are maintained. *See also* 1739 TOOL; 1798 PHY.

1775

Biology

Systema entomologiae by German naturalist Johann Fabricius [b. January 7, 1745, d. March 3, 1808] classifies insects based on the structure of mouth organs rather than the wings. *See also* 1737 BIO; 1805 BIO.

Chemistry

Essay of Electric Attractions by Torbern Olaf Bergman [b. Katrineberg, Västmanland, Sweden, March 20, 1735, d. Medevi, Sweden, July 8, 1784] is a study of chemical affinities (how strongly one chemical reacts with another). *See also* 1777 CHEM.

The Lunar Circle of Birmingham, England, is reorganized as the Lunar Society, which has its first meeting on December 31. *See also* 1765 COMM.

Ecology & the environment

Physician Sir Percival Potts suggests that chimney sweeps in London develop cancers of the scrotum and of the nasal cavity as a result of exposure to soot, the first indication that environmental factors can cause cancer. *See also* 1953 MED.

Energy

French missionaries in the Ohio valley and George Washington independently observe burning natural gas that escapes from the ground. *See also* 1778 CHEM.

James Watt on May 22 obtains a 25-year extension of his patent for his separate-condenser steam engine. *See also* 1769 ENER; 1776 ENER.

Alessandro Volta describes his *eletrofore perpetuo* (electrophorus), a device for producing and storing a charge of static electricity; this device replaces the Leiden jar and eventually leads to modern electrical condensers. *See also* 1746 ENER; 1800 ENER.

Pierre-Simon Girard [b. Caen, France, November 4, 1765, d. Paris, November 30, 1836]



Alessandro Giuseppe Antonio Anastasio, Count Volta (a.k.a. Alessandro Volta)

[b. Como, (Italy), February 18, 1745, d. Como, March 5, 1827]

Volta is remembered for his invention in 1799 of the first electric battery, chemically producing an electric current with plates of two different metals soaking in brine. About 25 years earlier, Volta invented the electrophorus, a device for creating large amounts of static electricity still used today. In 1778 he was the first to isolate the gas methane (CH_4).

invents a water turbine. See also 1798 MATR.

II Food & agriculture

Farmers in colonial America report that serious soil erosion is resulting in poor harvests.

♥ Medicine & health

Théophile de Bordeu [b. 1722, d. 1776] in Paris postulates that secretions of glands reach other organs by the way of the bloodstream. See also 1902 BIO.

William Withering [b. Wellington, England, March

1741, d. Birmingham, England, October 6, 1799] introduces digitalis to cure the dropsy associated with heart disease. See also 1785 MED.

I Tools

Jacques de Vaucanson develops an automatic weaving loom in which the index fingers (which lift and lower the warp threads) are controlled by a perforated rotating cylinder. See also 1745 TOOL; 1801 TOOL.

→ Transportation

David Bushnell [b. Saybrook, Connecticut, c. 1742, d. Warrenton, Georgia, 1824] invents a hand-operated, one-man submarine, called the American Turtle. The submarine is the first device to employ the propeller for motive power in water, using propellers for both horizontal and vertical movement. See also 1620 TRAN; 1777 TOOL.

1776

◀ Anthropology

Anthropologist Johann Friederich Blumenbach [b. Gotha, Saxony (Germany), May 11, 1752, d. Göttingen, Saxony (Germany), January 22, 1840] writes *De generis humani varietate* ("on the natural varieties of mankind"). It divides humanity into four different races — Caucasian, Mongolian, American Indian, and Ethiopian.

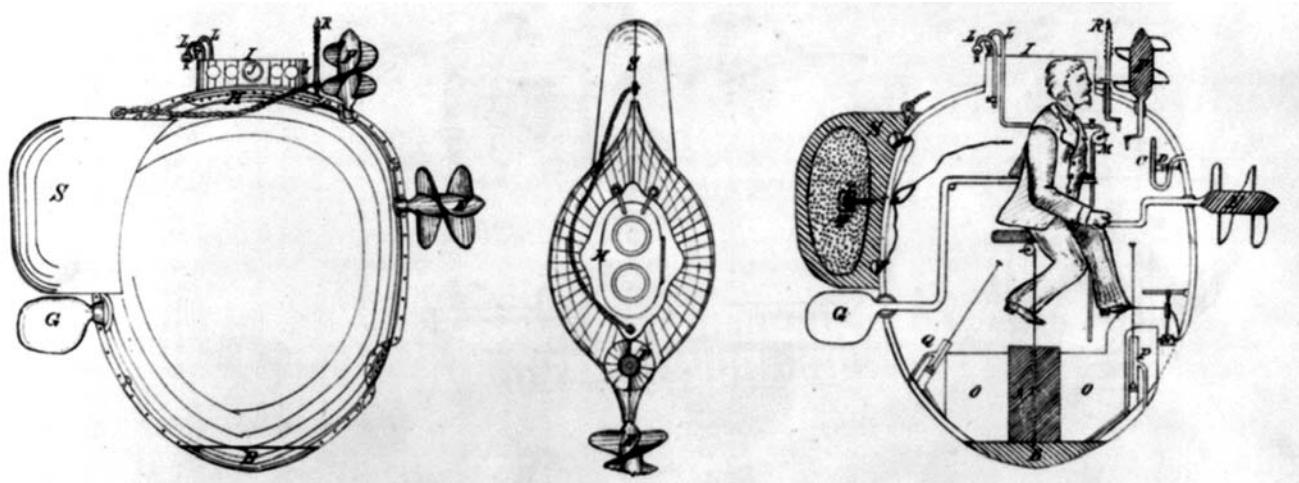
★ Astronomy

Johann Tobias Mayer publishes a small but good lunar map.

□ Chemistry

Karl Wilhelm Scheele and Torbern Bergman independently discover uric acid. See also 1774 CHEM; 1811 CHEM.

French chemist F. de Lassone prepares carbon monoxide. See also 1270 PHY; 1800 CHEM.



DRAWINGS OF BUSHNELL'S AMERICAN TURTLE The failure of the *Turtle*'s only mission came because the bomb supposed to be attached to a British warship in New York Harbor failed to attach, but the submarine proved its ability to maneuver in sea trials earlier and escaped the bomb blast and British ships. British commanders recognized the danger and moved the fleet further out to sea. The *Turtle* was later scuttled to prevent capture by the enemy.

Earth science

James Keir [b. 1726, d. West Bromwich, England, October 11, 1820] suggests that such rock formations as the Giant's Causeway in Ireland may have been caused by molten rock crystallizing as it cooled. *See also* 1797 EAR.

James Cook begins his last voyage of discovery, traveling to Kerguelen Island, New Zealand, Hawaii, and northeast of the Bering Strait. *See also* 1772 EAR; 1777 EAR.

Energy

The first two of Watt's steam engines are installed. *See also* 1775 ENER; 1781 ENER.

William Blakey patents in the Netherlands a high-pressure water-tube boiler. It fails to work, however, because the

copper tubes do not sustain the steam pressure. *See also* 1765 ENER; 1781 ENER.

Medicine & health

John Fothergill gives the first clinical description of trigeminal neuralgia (Fothergill's disease).

Steam engines power machines

Except for technical improvements made by John Smeaton, engineers in the middle of the 18th century built steam engines much the same way Thomas Newcomen designed his first engine.

Unlike Smeaton, who as a designer of machines naturally was led to the development of steam engines, the instrument maker James Watt started working with steam engines quite by chance. Watt had set himself up as the manufacturer of scientific instruments, and one of his first clients, the University of Glasgow, employed him to repair some of their scientific instruments. While repairing these instruments, he also worked with scientists, among them Joseph Black, and gained invaluable experience in physics. The university asked Watt to repair a model of a Newcomen engine. One of the first things Watt noticed was that the machine was extremely voracious for steam. Furthermore, most steam and heat were lost during the condensation of steam by a jet of water sprayed into the cylinder.

Watt reasoned that by keeping the cylinder hot at all times, which meant carrying out the condensation of steam in a separate vessel, he would be able to conserve steam and reduce fuel consumption. In 1765 he built a simple model of his steam engine with a separate condenser and found out that by avoiding the alternating heating and cooling of the cylinder he could save a lot of fuel. Watt also insulated the cylinder itself, reducing the loss of steam inside the cylinder by condensation on cold cylinder walls. Watt obtained a patent for "a new method of lessening the consumption of steam and fuel in fire engines" in 1769.

Later Watt realized another advantage of the separate condenser: The cylinder could be made double-acting. In a double-acting cylinder, steam is alternately directed above and under the piston, doubling the work that can be supplied by the piston.

Joseph Black had also brought Watt into contact with the industrial pioneer John Roebuck, and Watt and Roebuck formed a partnership. The partners started building an experimental beam engine (a steam engine whose action is to raise and lower a long lever, or beam) near Roebuck's residence, but the project did not

progress. Roebuck had financial difficulties and Watt had to keep other commitments to earn his living. Roebuck went bankrupt in 1773 and Matthew Boulton, who had shown interest in Watt's machine since 1769, bought Roebuck's two-thirds share in the enterprise. Boulton proposed to build a factory to produce Watt engines "for all the world." In 1775 Boulton succeeded in extending Watt's patent, which would have expired before any machines could have been produced. In 1776 Boulton and Watt started work on the two first separate-condenser engines ordered, one sold to a coal mine for a pump and one sold to the ironmaster John Wilkinson, who needed a machine for pumping bellows for a blast furnace. Wilkinson had also just patented a new boring mill for cylinders. Use of Wilkinson's borer allowed the manufacture of cylinders for the steam engines to much higher specifications. The first two Watt engines were immediate successes, consuming only a quarter of the fuel of Newcomen engines of similar power.

As soon as Watt developed his engine, Boulton proposed building a machine that could supply rotary motion. The idea of using a connecting rod and crank was not apparent because the stroke length of the beam machines used to vary considerably, and it was not clear that a flywheel, crankshaft, and connecting rod would solve this problem entirely. In any case, the crank used in conjunction with a steam engine was patented by another machine builder. Watt was forced to develop another method, and he chose to use the "Sun and planet" gear to obtain rotary motion. The piston rod was rigidly connected to the beam via a system of rods forming a parallelogram; the arrangement came to be called parallel motion, although the important result was rotary motion.

Although the reciprocating motion supplied by the first steam engines was suitable for pumping water or powering bellows, it was the adaptation of those engines to rotary motion that made the Industrial Revolution possible. Previously, factories had to be set up near rivers and streams that could deliver waterpower, often far from cities and the necessary work force. Rotary steam power changed this situation completely. Factories were built in cities, near transport channels, such as rivers and canals, and near abundant work forces.

* Physics

Pierre-Simon Laplace states that if we know all of the forces on all objects at any one time, then we can completely predict the future.

I Tools

John Wilkinson uses a steam engine to create the blast of air in a blast furnace, increasing its efficiency dramatically. By the end of the century there will be 24 steam-driven blast furnaces in England. *See also* 1748 MATR.

Adam Smith [b. Kirkcaldy, Scotland, June 5, 1723, d. Edinburgh, July 17, 1790], in his book *Inquiry into the Nature and Causes of the Wealth of Nations*, defines the origin of mechanization and invention of machines as a result of the division of labor.

1777

□ Chemistry

Carl Friedrich Wenzel [b. (Germany) 1740, d. February 27, 1793] determines the reaction rates of various chemicals, establishing, for example, that the amount of metal that dissolves in an acid is proportional to the concentration of acid in the solution. *See also* 1775 CHEM.

Karl Wilhelm Scheele's *Chemische Abhandlung von der Luft und Feuer* ("chemical treatise on air and fire") describes his experiments for producing oxygen and notes that air consists of "fire air" (oxygen) and "foul air" (nitrogen). *See also* 1774 CHEM; 1778 CHEM.

Henry Cavendish, having learned that Priestley observes

dew when hydrogen is burned, experiments further. He observes that the combustion of hydrogen and oxygen produces water, although he interprets this in terms of the later-to-be discredited phlogiston theory. *See also* 1773 CHEM; 1783 CHEM.

Lavoisier repeats the experiment of Henry Cavendish showing that hydrogen and oxygen combine to form water. Unlike Cavendish, Lavoisier realizes that he is dealing with a new gas, which he names hydrogen. *See also* 1774 CHEM; 1783 chem

⌚ Communication

Guide to Technology, published in Germany by Johann Beckmann [b. 1739, d. 1811], defines technology as the systematic study of technical procedures. *See also* 1776 TOOL; 1782 ENER.

⊕ Earth science

Nicolas Desmarest correctly proposes that basalt is formed from lava emitted by volcanoes. *See also* 1776 EAR; 1797 EAR.

➤ Energy

The first buildings in France since Roman times are heated by a warm-water central-heat-

ing system. *See also* 80 BCE ENER; 1784 ENER.

Σ Mathematics

Euler uses *i* to represent the square root of negative 1, the basis of the complex numbers, in a manuscript that will not be published until 1794. Gauss popularizes the symbol with his *Disquisitiones arithmeticæ*, published in 1801. *See also* 1685 MATH; 1798 MATH.

♥ Medicine & health

William Cullen [b. Hamilton, Scotland, 1720, d. 1790], in *First Line in the Practice of Physic*, introduces the term *neurosis* to define mental illness. *See also* 1791 MED.

I Tools

Charles Augustin Coulomb invents the torsion balance independently of John Michell, who had developed the device somewhat earlier. *See also* 1773 CONS; 1785 PHY.

David Bushnell invents the torpedo. *See also* 1775 TRAN.

➤ Transportation

The Grand Trunk Canal, officially opened in 1766 and combining the Trent and Mersey Canal with the Birm-

ingham Canal to the Severn, is finally complete. The canal, primarily the design of James Brindley, who dies before it is completed, passes through five tunnels, including a famous one-way tunnel at Harecastle that is 2633-m (2880-yd) long. *See also* 1766 TRAN.

1778

↗ Biology

Flore française ("French plants") by naturalist Jean-Baptiste Lamarck discusses French plant life and will lead to his position after 1781 as Royal Botanist.

□ Chemistry

Alessandro Volta studies inflammable air from marshes and discovers methane gas. *See also* 1775 ENER.

Lavoisier announces that air consists of two different gases, one that is respirable, which we now call oxygen, that is one-quarter by volume, and another that is not respirable that occupies the other three-quarters, which we now call nitrogen. (Modern values are 20.05 percent oxygen, 78.08 percent nitrogen, the remainder other gases.) *See also* 1777 CHEM.

Jean-Baptiste Pierre Antoine de Monet, chevalier de Lamarck (a.k.a. Jean-Baptiste Lamarck)

[b. Bazantin-le-Petit, France, August 1, 1744, d. Paris, December 28, 1829]

Lamarck was the first person to propose a theory of evolution. He suggested that evolution, which he called transformation, of a species takes place as the result of "a new need that continues to make itself felt" and that acquired characteristics gained during an organism's life can be inherited by the organism's offspring — a concept later disproved. Similarly, Lamarck correctly noted that Earth's surface is constantly transformed, resulting in dramatic changes over time.



Peter Jacob Hjelm [b. Sunnerbo Härad, Sweden, October 2, 1746, d. Stockholm, Sweden, October 7, 1813] discovers molybdenum (Mo).

Torbern Bergman's *De analysi aquarum* gives the first comprehensive analysis of mineral waters and also establishes quantitative analysis. *See also* 1782 EAR.

Communication

Botanist Sir Joseph Banks is elected president of the Royal Society. Although not a good administrator, his use of his large fortune to advance scientific causes keeps him in office until his death.

Construction

Joseph Bramah [b. Stainborough, England, April 13, 1748, d. London, December 9, 1814] patents an improved toilet with flushing water and a bowl encased in wood. *See also* 1589 CONS; 1865 TOOL.

Earth science

James Cook discovers the Hawaiian Islands on January 20. *See also* 1776 EAR.

Atlas et description minéralogique de la France ("atlas and mineral description of France") by Jean-Etienne Guettard and Antoine Grimoald Monnet [b. Chameix, France, 1734, d. Paris,

May 23, 1817], completed in 1781, is commissioned by the French government. *See also* 1770 EAR; 1794 EAR.

Medicine & health

John Hunter's *A Practical Treatise on the Diseases of the Teeth* classifies teeth into molars, bicuspids, cuspids, and incisors.

Tools

A lightning rod is installed on the two-century-old Genoa (Italy) lighthouse, which at 61 m (200-ft) in height has been a frequent lightning victim despite a nearby statue of St. Christopher intended to draw off the bolts. *See also* 1752 TOOL.

1779

Astronomy

The Comet Lexell passes as close to Jupiter as its inner satellites; it causes no disturbance in the path of the satellites and therefore its mass must be smaller than 1/5000th that of Earth. *See also* 1765 AST.

Biology

In *Experiments on Vegetables*, Jan Ingenhousz concludes that sunlight is essential for the production of oxygen by leaves. He discovers two distinct respiratory cycles in plants: At night

oxygen is absorbed and carbon dioxide is exhaled and during the day carbon dioxide is absorbed and oxygen is exhaled. *See also* 1773 CHEM.

Lazzaro Spallanzani studies the role of semen in fertilization and learns that the sperm must make physical contact with the egg for fertilization to take place. *See also* 1785 BIO; 1841 BIO.

Chemistry

On September 5 Lavoisier proposes the name *oxygen* ("acid forming") for the part of air that is respirable and responsible for combustion. Lavoisier incorrectly believes that oxygen is an essential ingredient for acids; later research will show that hydrogen is the acid-forming element.

Experiments and Observations on Animal Heat and the Inflammation of Combustible Bodies by Scotch-Irish naturalist Adair Crawford [b. Antrim, Ireland, 1748, d. Lymington, England, July 1795] develops methods of determining the specific heat of substances and treats heat generation in animals. *See also* 1818 CHEM.

Construction

The third of the three famous men named Abraham Darby [b. 1750, d. 1791], starting in



Jan Ingenhousz

[b. Breda, Holland, December 8, 1730, d. Wiltshire, England, September 7, 1799]

Building on experiments of Joseph Priestley that showed that plants give off oxygen, Ingenhousz laid the groundwork for understanding photosynthesis when he demonstrated that green leaves absorb carbon dioxide and release oxygen only in sunlight. In darkness, he showed, leaves — like animals and nongreen plant parts at all times — absorb oxygen and give off carbon dioxide. A noted physician, Ingenhousz was among the first to inoculate against smallpox; unlike the safer method later developed by Edward Jenner, however, Ingenhousz used live smallpox viruses.

1775, builds the famous Iron Bridge over the river Severn at Coalbrookdale, the first really large iron structure — 60 m (196 ft) long and built entirely of cast iron. *See also* 1750 MATR.

Charles Augustin Coulomb proposes using compressed air and caissons for underwater construction. *See also* 1777 TOOL.

Earth science

Comte de Buffon argues in *Epoques de la nature* ("time periods of nature") that 75,000 years have elapsed since Creation, the first modern speculation that Earth is older than Biblical evidence shows,



Sir Joseph Banks

[b. London, February 13, 1743, d. Isleworth, England, June 19, 1820]

Interested in plants from childhood, Banks helped make botany an academic discipline, developed an extensive botanical collection (donated to the British Museum), and helped establish Kew Gardens in London. He undertook several major collecting trips, the most famous of which was his around-the-world voyage aboard the *Endeavour* on the 1768–71 expedition led by James Cook. This expedition made known to Europeans such wonders as the marsupial animals of Australia.

which is about 6000 years. *See also* 1652 EAR; 1830 EAR.

Horace de Saussure coins the term *geology* in his work *Voyages dans les Alpes* ("travels in the Alps"), published between 1779 and 1796. He correctly analyzes why glaciers move, but wrongly thinks that erratic boulders are moved by streams of water rather than carried by ice. *See also* 1818 EAR.

I Tools

Samuel Crompton [b. Firwood, England, December 3, 1753, d. Bolton, England, June 26, 1827] develops the spinning mule, a cross between the spinning jenny and the water-frame spinning machine. It is capable of spinning either warps or wefts. *See also* 1769 TOOL.

✈ Transportation

Velocipedes, a type of early bicycle, appear in Paris. *See also* 1790 TRAN.

1780

Biology

Lazzaro Spallanzani's *Dissezzazioni de fisica animale e vegetale* ("dissertation on animal and plant physics") interprets the process of digestion. *See also* 1752 BIO.

Chemistry

Karl Wilhelm Scheele discovers lactic acid. *See also* 1776 CHEM; 1782 CHEM.

Communication

John Adams founds the American Academy of Arts and Sciences in Boston. George Washington, Benjamin Franklin, and Thomas Jefferson are among the first members.

The fountain pen is invented. *See also* 1864 COMM.

James Watt invents a form of copying in which a special ink is used for making the original. The ink then transfers to a sheet of paper pressed into it. The descendants of this method, using a purple dye, were common in schools before the introduction of dry copying. *See also* 1937 COMM.

■ Construction

Architect Victor Louis [b. Paris, May 10, 1731, d. July 2, 1800] uses an iron frame for building a theater at Bordeaux in France. *See also* 1845 CONS.

⊕ Earth science

The huge skull of a creature later named a *Mosasaur* is found in a stone quarry near the Meuse River in the Netherlands. Bones from the same creature had been found earlier. The fossil will become the first remains of a giant, prehistoric reptile to be so identified when it is examined by Georges Cuvier in 1795. *See also* 1766 EAR; 1795 EAR.

↗ Energy

James Pickard, probably tipped off by one of James Watt's assistants, patents a method of using a crank wheel to produce rotary motion with a steam engine. Matthew Boulton or his partner James Watt recognizes the importance of this and Watt begins to develop another method to turn reciprocating into rotary motion. *See also* 1781 ENER.

Σ Mathematics

Jean le Rond D'Alembert's *Opuscules mathématiques* ("mathematical pamphlets"),

collecting in eight volumes many of D'Alembert's shorter works, which are not published elsewhere, concludes, having started publication in 1761. Because D'Alembert is among the first to understand the value of functions, the set, which contains D'Alembert's work on limits, forms an important advance in calculus. *See also* 1748 MATH.

1781

★ Astronomy

William Herschel discovers a planet on March 13, although at first he believes it to be a comet. Anders Lexell, among others (including Herschel), calculates the orbit of the moving body discovered by Herschel, establishing that it is a new planet. Herschel originally proposes the name Georgium Sidus for the new planet (after England's King George III), but the international astronomical community, maintaining the old tradition of naming planets after the gods of Antiquity, settles on the name Uranus. *See also* 1846 AST.

Charles Messier publishes in *Connaissance des temps pour 1784* (published in 1781 despite the date) his final catalog, which now contains more than 100 star clusters and nebulae that might be mistaken for comets. Many are still called by his catalog numbers, such as M13, the giant star cluster in Hercules, and M31, also known as the Andromeda Galaxy. *See also* 1754 AST.

↗ Biology

Peter Christian Abildgaard [b. Denmark, 1740, d. 1801] discovers that a tapeworm requires

more than one host. The idea that some parasites alternate hosts was not widely accepted until confirmed by Gottlob Küchenmeister [b. 1821, d. Dresden, Germany, 1890] in 1852 in his study of trichinosis.

▷ Chemistry

Karl Wilhelm Scheele studies the composition of the mineral calcium tungstate, now called scheelite, but fails to pin down tungsten as a new element.

⊕ Earth science

René-Just Haüy [b. St.-Just-en-Choisée, France, February 28, 1743, d. Paris, June 3, 1822] drops a piece of calcite and his examination of the fragments leads to the geometrical law of crystallization. *See also* 1783 EAR.

↗ Energy

James Watt patents five ways to change the power from a steam engine from reciprocating to rotary motion. The most successful is called the sun-and-planet drive. The "sun" is a toothed wheel whose back-and-forth motion causes a second toothed wheel, the planet, to rotate. *See also* 1776 ENER; 1782 ENER.

Jonathan Hornblower [b. 1717, d. 1780] invents the compound steam engine; steam enters one high-pressure cylinder and subsequently expands in a second, larger cylinder. Because of the low steam pressure used at that time, however, the machine is less efficient than the Watt engine. *See also* 1776 ENER; 1811 ENER.

Charles Augustin Coulomb writes on the construction of windmills. *See also* 1779 CONS; 1784 MATR.

When was the Industrial Revolution?

The French coined the term Industrial Revolution in the 19th century as an analogy to their own political revolution. Although the phrase is in common use, it is not always clear what this phenomenon was or even when it occurred.

For example, it has been pointed out that humans underwent an industrial revolution at the beginning of the Bronze Age; yet, it is clear that the Industrial Revolution is something else. One theory holds that the Industrial Revolution happened when people stopped using human and animal power and began using inanimate power sources; this could place the Industrial Revolution as early as the first extensive use of wind and waterpower — medieval times in the West and somewhat earlier in China. A different suggestion is that it began when mills began to centralize the production of textiles. This might be interpreted as occurring when fulling mills (mills to work cloth so that it is fuller) began, in the 13th century. Perhaps the date ought to be tied to the large-scale production of iron in blast furnaces, which employed workers in something like a factory system. That postpones the revolution to the 15th and 16th centuries. Or maybe it started with the first factory, probably the six-story English silk-thread mill built in 1719 that employed 300 workers, mostly women and children.

A few years after that first factory John Kay made one of the key inventions that started what most historians would call the Industrial Revolution: the flying shuttle, which made weaving much faster. And a few years before that factory Abraham Darby discovered how to make steel using coal instead of wood — actually, coke instead of charcoal. This allowed for a greater output of cheap steel, since coal was more plentiful than wood at that time in England.

The problem with using these early 18th-century inventions to date the revolution is that few employed them in their early days. It was over 50 years before other steel makers started following Darby's example; and weavers afraid of losing their jobs destroyed Kay's loom and sent him packing to France.

About 1750, however, cotton workers, with less of a tradition behind them than the wool workers who had attacked Kay's loom, started using the flying shuttle. This set into motion a chain of events that revolutionized the textile industry. With the flying shuttle, cotton workers were able to weave so much faster that they ran out of yarn. Seeing an opportunity, James Hargreaves invented a machine that multiplied the amount of yarn

produced, the spinning jenny. This time the spinners were upset, and they destroyed some of Hargreaves's machines, but the cat was out of the bag.

The spinning jenny could make only one of the two types of yarn needed for weaving. Richard Arkwright also saw opportunity knocking: He invented the water frame, a machine that produced the other type of yarn. Unlike the spinning jenny, the water frame was too large and too expensive to put in a cottage. Arkwright had to build a factory to house his machine; he is, in fact, considered the founder of the modern factory system. By 1769 the Industrial Revolution had definitely begun; many date the start back to the 1740s when the cotton weavers first adopted the flying shuttle.

However, there is another key invention that is not yet in place in 1769. Since at least 1629, when Giovanni Branca suggested using steam to propel a turbine, people had been experimenting with steam power. Branca was followed by the Marquis of Worcester in England, Denis Papin in France, and, again in England, Thomas Savery. Savery, at the very end of the 17th century, was the first to make a practical steam engine, known as the Miner's Friend. It wasn't very efficient, however, and only a few were installed. Soon Thomas Newcomen recognized the opportunity and developed a greatly improved steam engine that was more along the lines of the modern engine. Newcomen then got together with Savery, and the Newcomen version of Savery's engine was successfully manufactured and sold to drain mines. Over 100 Newcomen engines were installed during the 18th century.

An engineer at Glasgow University, James Watt, in 1765 developed a new device, the steam condenser, which greatly improved the efficiency of the Newcomen engine. Ten years later, Watt teamed with a manufacturer of iron products, Matthew Boulton of Birmingham, to manufacture his new engine. Boulton had access to the technology needed to make finely machined parts that gave the Watt engine greater efficiency and durability. Boulton also convinced Watt in 1781 to convert the engine from a simple pump to a device producing rotary power — the first steam engine that could power other machinery. Four years later the first steam-powered cotton mill opened in Papplewick, Nottinghamshire. By this date, the revolution part of the Industrial Revolution in England had been completed. It would occur 30 years later in France and 20 years after that in Germany and the United States. Assigning the revolution a single date would be misleading. It took from the 1740s until the 1780s; after that came consolidation of power by the revolutionaries.

Σ Mathematics

Joseph-Louis Lagrange expresses in a letter to his mentor Jean le Rond D'Alembert the fear that mathematics

has reached its limit and that no further progress can be made.

Immanuel Kant's *Critique of Pure Reason*, which tries to

reconcile empiricism and rationalism, declares the Euclidean space is the pure product of thought and that no other possible geometry can exist, since there is only

one way to think. See also 1766 MATH.

❖ Physics

Johan Carl Wilcke introduces

the concept of specific heat.
See also 1739 PHY.

Charles Augustin Coulomb's *Théorie des machines simples* ("theory of simple machines") is a study of friction.

I Tools

To build his telescopic equipment, William Herschel uses a small brass-and-steel lathe that he operates with a foot pedal; a flywheel regulates and maintains the speed. This is state-of-the-art equipment at the time. See also 1760 TOOL.

→ Transportation

Claude François Marquis de Jouffroy d'Abbans [b. Rœcs sur Rognan, France, 1751, d. Paris, 1832] designs (and later builds) the *Pyroschape*, a steam-engine-powered paddleboat; it is tested successfully on the Saône River near Lyon in 1783. See also 1670 TRAN; 1783 TRAN.

1782

★ Astronomy

The 17-year-old, deaf-mute astronomer John Goodricke [b. Groningen, Holland, September 17, 1764, d. York, England, April 20, 1786] becomes the first to suggest the correct explanation for variation in the light from the star Algol, which is caused by an invisible companion star. Goodricke is also the first to calculate the correct period for Algol's variations. See also 1638 AST; 1784 AST.

□ Chemistry

Lavoisier observes that total weight does not change in chemical reactions, establishing the first version of the law of conservation of mass. See also 1748 PHY; 1789 CHEM.

Austrian mineralogist Franz Joseph Müller [b. Nagyszeben, Transylvania, July 1, 1740, d. Vienna, Austria, October 12, 1825] discovers tellurium (Te).

Karl Wilhem Scheele prepares hydrocyanic acid. See also 1780 CHEM; 1784 CHEM.

● Earth science

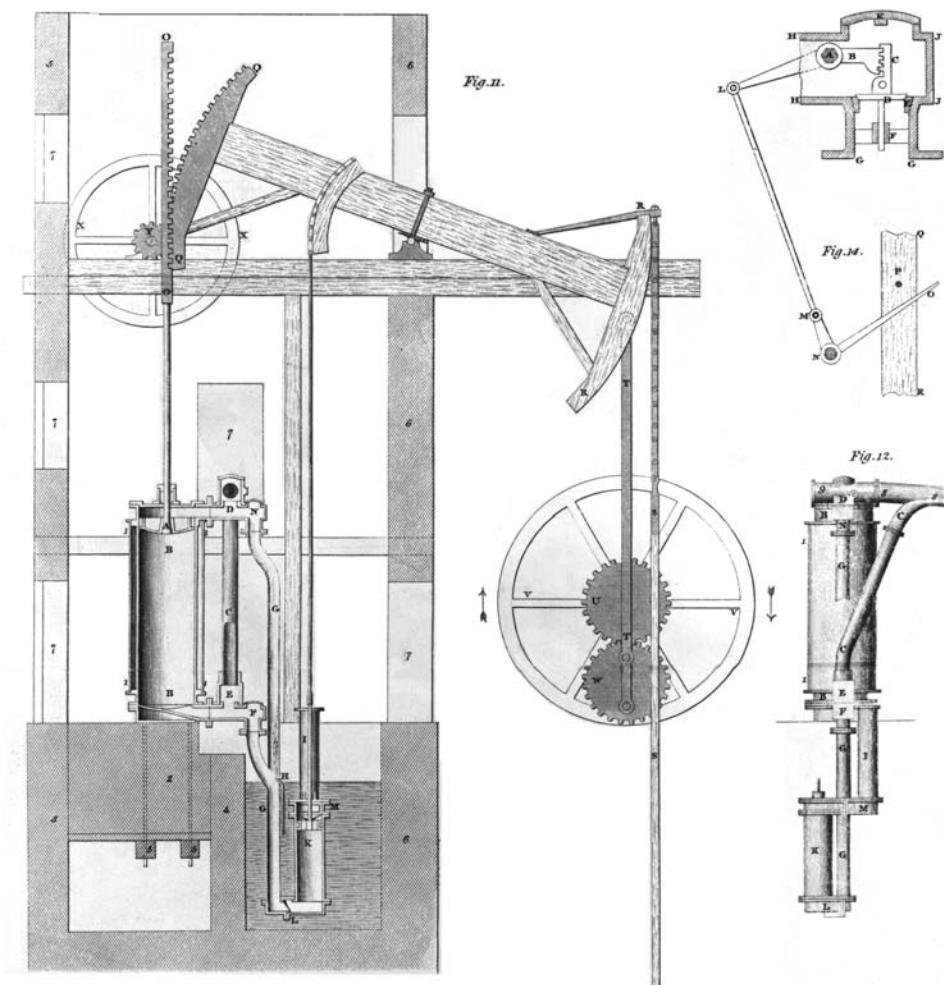
Torbern Bergman in *Scia-graphia regni mineralis* ("outlines of the mineral king-

dom") lays the foundation for the chemistry of minerals by classifying minerals by their chemistry. See also 1778 CHEM.

↗ Energy

Lazare Carnot [b. Burgundy, France, May 13, 1753, d. Magdeburg, Germany, August 2, 1823], in his *Essai sur les machines en général* ("essay on machines in general"), uses scientific arguments to discuss the efficiency of machines.

James Watt patents a double-acting steam engine: Steam is admitted alternatively on both sides of the piston, making the engine more efficient. He also patents his principle of cutting off steam before the piston completes the stroke. The piston is still driven by the expansion of the steam, but such a machine saves fuel. See also 1781 ENER; 1783 ENER.



WATT'S DOUBLE-ACTING STEAM ENGINE OF 1782 The engine is called "double-acting" because steam is first let in below the piston to lift it, and then as the piston reaches the top, steam is used to drive the piston downward. Note the sun-and-planet arrangement that changes the reciprocating motion of the piston into rotary motion.

Food & agriculture

Louis-Jean-Marie Daubenton [b. Montbard, France, May 29, 1716, d. Paris, January 1, 1800] writes *Instruction pour les bergers et pour les propriétaires de troupeaux* (“advice to shepherds and owners of flocks on the care and management of sheep”). He introduces merino sheep to France.

Materials

Josiah Wedgwood invents the pyrometer for checking the temperature in furnaces used to fire pottery. *See also* 1763 MATR.

Mathematics

In a paper on gravitational attraction “*Recherches sur l’attraction des sphéroïdes*” (“researches on the attractions of shapes similar to spheres”—not published until 1785), Adrien-Marie Legendre [b. Toulouse, France, September 18, 1752, d. Paris, January 9, 1833] describes “Legendre polynomials,” the polynomial solutions of an important differential equation. These are used to solve the problems of gravitational attraction for bodies formed by rotating a curve about an axis. *See also* 1784 MATH.

Pierre-Simon Laplace develops a mathematical operation now called the Laplace transform to solve an integral equation, although he does not realize that he is working with a new class of equations. *See also* 1823 MATH.

1783

Astronomy

William Herschel discovers that the “star” known as al-Kaid, or Keid to the Arabs, is

formed from two separate stars. Today we recognize three stars in the small system, now called 40 Eridani from its location in the constellation Eridanus and its Flamsteed number. *Star Trek* fans may recognize it as the site of the planet Vulcan, home to Spock. Herschel proceeds to publish his first list of double stars, which with two additional lists, locates more than 800 pairs. *See also* 1802 AST.

Pierre-Simon Laplace’s *Recherches sur le calcul intégral et sur le système du monde* (“investigations in integral calculus and the system of the world”) contains a new method for solving the equations of motion of celestial bodies. *See also* 1801 AST.

Chemistry

In April, having learned of Priestley’s and Cavendish’s experiments with burning hydrogen and obtaining water, James Watt proposes to Priestley that water is a compound of “dephlogisticated air and inflammable air” (that is, oxygen and hydrogen). *See also* 1773 CHEM; 1784 CHEM.

On November 12, Lavoisier reports to the Royal Academy of Sciences that his experiments, conducted in 1777, show that water is not an element, but a compound of “dephlogisticated air and inflammable air.” *See also* 1777 CHEM; 1784 CHEM.

Lavoisier’s *Reflexions sur la phlogistique* (“reflections on phlogiston”) depicts the contradictions and weaknesses of the phlogiston theory of combustion. *See also* 1697 CHEM; 1791 CHEM.

Mineralogist Don Fausto D’Elhuyar [b. Logroño, Spain,

October 11, 1755, d. Madrid, Spain, January 6, 1833] and his brother Juan José D’Elhuyar [b. 1754, d. 1796] discover tungsten (W).

Oxidized hydrochloric acid (then known as oxymuriatic acid, since the unrecognized element chlorine was called muriatic acid) is introduced for bleaching of fabrics; this is the beginning of bleaching with chlorine. *See also* 1799 MATR.

Chemist Nicolas Leblanc [b. Issoudun, France, December 6, 1742, d. St. Denis, France, January 16, 1806] wins a prize set by the French government for finding a practical way of making sodium hydroxide and sodium carbonate from salt, although the money is never paid. Among other benefits, the Leblanc process makes possible the large-scale manufacture of soap. *See also* 1846 MATR.

Karl Wilhelm Scheele discovers glycerin.

Communication

Valentin Haüy [b. St. Just, France, February 28, 1743, d. Paris, June 3, 1822] in France introduces an alphabet for blind people; it consists of simplified italic characters embossed in paper. *See also* 1784 COMM.

British printer Thomas Bell develops cylinder printing for fabrics. *See also* 1790 TOOL.

Earth science

The volcano Laki in Iceland begins a disastrous eruption that eventually kills 10,000 Icelanders, one-fifth the population of the island. The event leads Benjamin Franklin to speculate that dust and gases from a volcanic eruption could

result in lower temperatures by screening out some of the radiation from the Sun. The eruption apparently cools parts of northwestern Alaska and Japan so much that there will be no summer in the following year. This change in the weather is attested to not only by tree rings from Alaska but also by oral traditions among the Kauverak people who recall a great famine that resulted from the cold weather. *See also* 1815 EAR.

Engraver Abel Buell [b. Killingworth, Connecticut, 1742, d. New Haven, Connecticut, 1825] produces the first map of the United States as a new nation.

Jean Romé de Lisle’s *Cristallographie* (“crystallography”) formulates the law of constancy of interfacial angles. *See also* 1781 EAR.

Energy

James Watt completes construction of his first rotary-motion steam engine; the piston rod is connected to a “sun-and-planet” gear that translates the back-and-forth action into rotary motion. Steam is admitted to the cylinder during both strokes of the piston by a set of valves operated by a system of levers known as parallel motion. *See also* 1781 ENER; 1784 ENER.

Martinus van Marum [b. Delft, Netherlands, March 20, 1750, d. Haarlem, Netherlands, December 26, 1837] builds in Haarlem the largest electrostatic machine of its time. It consists of two 1.5 m- (5-ft) disks that by friction generate a voltage high enough to produce sparks 60 cm (2 ft) long. *See also* 1787 ENER.

II Food & agriculture

American inventor Oliver Evans [b. Newport, Delaware, September 13, 1755, d. New York, April 15, 1819] invents a totally mechanized flour mill, the first ever to allow a continuous flow of wheat to be ground into flour. *See also* 1662 FOOD; 1810 FOOD.

The first plow-making factory opens in England. *See also* 1803 FOOD.

I Tools

Horace de Saussure in *Essais sur l'hygrometrie* ("essay on measuring humidity") describes how to construct a hygrometer from human hair that can measure relative humidity. *See also* 1820 TOOL.

→ Transportation

On June 5, the brothers Joseph-Michael [b. Vidalon-les-Annonay, France, August 26, 1740, d. Balaruc-les-Bains, France, June 26, 1810] and Jacques-Etienne Montgolfier [b. Vidalon-les-Annonay, January 6, 1745, d. Serrières, France, August 1, 1799] demonstrate the hot-air balloon at Annonay. *See also* 1785 TRAN.

On August 27 physicist Jacques-Alexandre Charles [b. Beauvais, France, November 12, 1746, d. Paris, April 7, 1823] builds the first hydrogen balloon, six weeks after the Montgolfier demonstration flight. Later in 1783 he begins a series of balloon ascents.

On November 21 Jean-François Pilâtre de Rozier [b. Metz, France, March 30, 1756, d. Boulogne-sur-Mer, France, June 16, 1785] and François Laurent, Marquis d'Arlandes, make a 25-minute flight over Paris in a hot-air balloon

designed by the Montgolfier brothers, becoming the first human beings to fly. *See also* 1784 TRAN.

Louis Sébastien Lenormand, influenced by accounts from China, becomes the first Westerner to use a form of parachute, the name of which is his invention — although Leonardo da Vinci had sketched a form of parachute two centuries earlier. According to one account, he demonstrates the principle by leaping from a tree and slowing his descent with two parasols. *See also* 90 BCE TRAN; 1793 TRAN.

Jacques-Constantin Périer operates a steamship on the Seine in France while Jouffroy d'Abbans travels the Saône River with a paddle-wheel steam boat. *See also* 1787 TRAN.

1784

▲ Archaeology

Statesman and scholar Thomas Jefferson [b. Shadwell, Virginia, April 13, 1743, d. Monticello, Virginia, July 4, 1826] investigates mounds built by Native Americans, making careful notes on stratigraphy. This earns him the title the father of American archaeology. While his various investigations of Native American burial sites, plant breeding, and fossils reveal no new scientific concepts of significance, Jefferson remains the closest the United States has come to having a scientist as president.

★ Astronomy

Edward Pigott [b. Middlesex, England, 1753, d. Bath, England, June 27, 1825] discovers

the variable star Eta Aquilae. At this time fewer than a dozen variables are known. *See also* 1782 AST; 1795 AST.

John Michell suggests that some stars may be so large that light cannot escape from their gravitational pull, essentially the concept of a black hole. *See also* 1798 AST.

□ Chemistry

Karl Wilhelm Scheele discovers citric acid. *See also* 1782 CHEM.

Henry Cavendish announces his discovery of the composition of water to the Royal Society. *See also* 1783 CHEM.

● Communication

Valentin Haüy prints his first book using his system of raised letters to enable the blind to read. *See also* 1783 COMM; 1824 COMM.

The first mail coach used in England leaves Bristol for London and covers the distance in 17 hours; mail is transported by coach until 1846, when the bulk of the mail begins to travel by train. *See also* 1550 COMM; 1830 COMM.

▼ Energy

Swiss chemist Aimé Argand [b. Geneva, Switzerland, 1755, d. Geneva, October 24, 1803] patents the first really bright lamp (still known as the Argand lamp), which burns oil in a wick between two concentric tubes, producing a circular flame with two sources of oxygen. A glass chimney provides constant air flow as it protects the flame from irregular breezes. *See also* 1800 ENER.

Jean-Pierre Minckelers is the first to use coal gas for light-



BURNER FOR ARGAND LAMP The novel burner design by Aimé Argand (not the Argand who developed representation of complex numbers) holds a circular wick whose flame receives oxygen from both inside and out, burning more brightly than a simple linear wick.

ing, which is followed in the next year or two by other experiments in coal-gas lighting by the English and Germans. *See also* 1786 ENER.

James Watt uses steam pipes to heat his office, the first use of "steam heat." *See also* 80 BCE ENER; 1830 ENER.

II Food & agriculture

Scottish inventor Andrew Meikle [b. Scotland, 1719, d. Houston Mill, near Dunbar, Scotland, November 27, 1818] invents the threshing machine, designed to separate grain from straw without manual flailing or trampling on the harvested wheat or rye; its basic design is still used today. *See also* 1834 FOOD.

◊ Materials

Inventor Henry Cort [b. Hampshire, England, 1740, d. 1800] patents the puddling process (also known as the reverberatory furnace) for making wrought iron from melted iron instead of hammering it. The process, which greatly lowers the price of

wrought iron by increasing the amount turned out by a single worker by a factor of 20 to 30, is one of the key inventions of the Industrial Revolution. He also perfects the rolling mill with grooved rollers. *See also* 1762 MATR; 1843 MATR.

Gaspard Monge liquefies sulfur dioxide, the first chemist to liquefy a substance normally a gas. *See also* 1895 MATR.

Charles Augustin Coulomb writes on the torsional (twisting) elasticity of metal and

silk fibers. *See also* 1781 ENER; 1822 MATR.

S Mathematics

Adrien-Marie Legendre continues his work on Legendre polynomials, the polynomial solutions of a differential

equation describing gravitational attraction of spheroids. He determines properties of the polynomial coefficients and a simple form of the equation for the gravitational field. *See also* 1782 MATH; 1785 AST.

Flight

When people before the Montgolfier brothers thought of human flight, they pictured birds. Leonardo da Vinci was one of the few who proposed a different concept, the helicopter. But early in the 17th century the barometer was invented by Evangelista Torricelli, and Blaise Pascal used it to show that not only does air have weight, but also air density decreases with altitude. Soon the Jesuit monk Francesco de Lana realized that an evacuated globe should float on the heavier air. A Dominican friar, Joseph Galien, pictured capturing less dense air from the top of a mountain and dragging it downhill until it reached a level that would cause a craft attached to it to float. These impractical schemes embodied the idea that flight could be accomplished by the quiet mechanism that buoys a ship in water instead of by frantic activity.

Joseph and Jacques Etienne Montgolfier came from a family of paper makers, so it should come as no surprise that their idea for flight would be realized in paper. All accounts credit older brother Joseph with the original notion, but differ on whether it was inspired by watching bits of burning paper fly into the sky or by reading about experiments that described different gases with different weights. The brothers are thought never to have understood that a hot-air balloon floats because warm air is less dense than cold air. Instead, they believed that burning produced a gas different from air that was also lighter than air. In any case, Joseph began in 1783 with a small paper balloon filled with hot air by holding it over a fire. A stronger silk balloon, similarly inflated, rose to about 21 m (70 ft). By June 4 of that year the brothers had made a sphere 11 m (36 ft) in diameter of linen lined with their family's paper to retain the gas. Their first public demonstration was in Annonay, France, south of Lyon and west of Grenoble. The balloon rose to a considerable height and floated in the air for ten minutes, coming down about 2.4 km (1.5 mi) away from the launch site. On landing, however, the fire suspended below the balloon lit the paper and the balloon burned. Word of this experiment quickly reached Paris. A public fund was set up in Paris to have a local scientist, Jacques Charles, duplicate the Montgolfier feat.

Charles, however, did not know how the Montgolfiers got their balloon to fly. He had been experimenting with hydrogen, which he knew to be lighter than air. Therefore, he began constructing a hydrogen balloon. He had to produce thousands of times as much free hydrogen as had ever been previously made — hydrogen had been known for less than 20 years. Charles and his assistants managed not to blow themselves up and succeeded in conducting the semipublic experiment — you had to have a ticket to get close to the 3.6-m (12-ft) balloon. When released, it shot straight up and quickly disappeared.

In the meantime, Jacques Etienne Montgolfier was also in Paris trying to arrange for a public demonstration of his own. He secured the support of Louis XVI and funding from the government. The second full-size hot-air balloon was 21 m (70 ft) tall, 12 m (40 ft) wide, and decorated like 18th-century wallpaper. This was because it was constructed with the help of another paper manufacturer, Jean-Baptiste Réallon, who made wallpaper. Unfortunately, the first attempt to fly the balloon ended in disaster when heavy rain dissolved the wallpaper. A third balloon was built, this time from taffeta coated with varnish. This balloon carried a sheep, a rooster, and a duck for about two miles in about eight minutes, landing gently enough not to harm the animals.

Competition now developed between the Montgolfier team and the Charles team to get the first human aloft. Although there are hints that the Montgolfier team might have achieved this even earlier, they definitely won with a public launch on the outskirts of Paris. François Pilâtre de Rozier and the Marquis d'Arlandes flew across Paris for over 20 minutes, but then lost their nerve and let the fire die so that the vehicle would descend. Ten days later, Charles and a member of his team made the first hydrogen balloon flight. But it was too late. The Montgolfiers would always be known as the people who gave humanity flight.

Before the end of 1783, several humans had made their first flights in hot-air balloons, sometimes called *Montgolfieres*, and also in Charles's hydrogen-filled devices. But it was not until January 10, 1784, that a Montgolfier brother ascended — Joseph was part of a successful flight in Lyon that included six other passengers. That was the only trip for Joseph, and Jacques-Etienne never did fly.

♥ Medicine & health

German poet and natural philosopher Johann Wolfgang Goethe [b. Frankfurt-am-Main (Germany), August 28, 1749, d. Weimar, Germany, March 2, 1832] discovers the human intermaxillary bone, a feature of the human upper jaw that is missing in most other mammals.

Benjamin Franklin invents bifocal eyeglasses, mounting half lenses for near and for distant vision in the same frames. *See also* 1450 MED.

* Physics

English clergyman George Atwood [b. London, 1745, d. London, July 11, 1807] writes *A Treatise on the Rectilinear Motion*, in which he describes “Atwood’s machine,” which accurately demonstrates the acceleration of a free-falling body. *See also* 1590 PHY.

I Tools

English army general Henry Shrapnel [b. England, June 3, 1761, d. March 31, 1842] invents the shrapnel shell.

Joseph Bramah invents an improved type of lock. A prize of 200 guineas is promised for anyone succeeding in picking the lock, which remains unpicked until 1851, when an American visitor spends 51 hours to achieve the task. *See also* 1818 TOOL.

↗ Transportation

Italian Vincent Lunardi [b. January 11, 1759, d. 1806] makes the first balloon ascent in England, using a balloon filled with hydrogen. *See also* 1783 TRAN; 1785 TRAN.

The Eider Canal, ordered dug by Danish King Christian VII

in 1777, uses three locks, the Eider River, and the Eider Lakes, to connect Kiel Bay on the Baltic with the North Sea. This is the prototype ship canal for international traffic, as well as the predecessor to the level Kiel Canal (Nord-Ostsee-Kanal) built a century later. *See also* 1777 TRAN.

James Watt covers the possibility of a steam-powered carriage in one of his patent applications, but does not pursue the idea. Indeed, when the first locomotives are tried out on rails, the by-then-retired Watt speaks privately against them. *See also* 1769 TRAN.

William Murdoch [b. Auchinleck, Scotland, August 21, 1754, d. Birmingham, England, November 15, 1839], an employee of steam-engine manufacturer Boulton & Watt, builds a working model of a steam-powered carriage. *See also* 1769 TRAN; 1789 TRAN.

1785

★ Astronomy

William Herschel's *On the Construction of the Heavens* gives the first reasonably correct description of the shape of the Milky Way Galaxy, although it underestimates its

size by three orders of magnitude and places the Sun near the center instead of where we now believe it to be, two thirds of the way to the edge. *See also* 1909 AST.

Pierre-Simon Laplace's *Théorie des attractions des sphéroïdes et de la figure des planètes* (“theory of attractions of spheroids and the shape of planets”) contains the partial differential equation named after him. This equation describes gravitational, electromagnetic, and other potentials, extending the work of Adrien-Marie Legendre. *See also* 1784 MATH.

❖ Biology

Lazzaro Spallanzani performs artificial insemination on a dog. *See also* 1779 BIO.

▷ Chemistry

Henry Cavendish determines the composition of the atmosphere. He finds that when all the oxygen and nitrogen have been removed, there is a small residue of an unknown gas, but this discovery is not followed up for over a hundred years, when the unknown gas will be found to be a mixture of argon, neon, krypton, and xenon. *See also* 1892 CHEM.

Cavendish produces nitric

acid by passing an electric spark through air. He also establishes its composition — hydrogen, nitrogen, and oxygen (HNO_3). *See also* 1784 CHEM; 1833 PHY.

⊕ Earth science

Theory of the Earth by James Hutton explains the principle of uniformitarianism: All geological features can be explained by changes now observable taking place over very long periods of time. In fact, Hutton concludes that there is no sign of Earth's beginning. *See also* 1779 EAR; 1830 EAR.

↗ Energy

William Murdoch builds a model of a high-pressure steam engine but does not gain approval for it from James Watt, who continues building atmospheric-pressure engines. *See also* 1800 ENER.

Σ Mathematics

Adrien-Marie Legendre's *Recherches d'analyse indétermine* contains the first statement of the law of quadratic reciprocity, an important theorem concerning prime numbers, but his proof of the theorem is flawed. *See also* 1796 MATH.

James Hutton

[b. Edinburgh, Scotland, June 3, 1726, d. Edinburgh, March 26, 1797]

After a successful career as a businessman, Hutton spent nearly 20 years as an amateur geologist before, in 1785, summarizing his views in *Theory of the Earth*: Earth is very old and present-day geological structures formed slowly by processes observable today, such as erosion and deposition. His phrase describing Earth as having “no vestige of a beginning, no prospect of an end” and related ideas came to be known as uniformitarianism. His idea that mountain building is caused by terrestrial heat is the Plutonic theory.



Neptunism v. Plutonism

During the Industrial Revolution, it became apparent that geology is important to commerce. Placement of canals, railways, and highways depends on geology, as does the location of coal and iron deposits. Furthermore, canal and railroad cuts exposed rock strata that had previously been covered with layers of soil.

It is not surprising, then, that geology, especially in England, entered a period of growth. Many people devoted themselves to the study of specific types of formations or strata. Two theorists in particular, Abraham Gottlob Werner and James Hutton, put forward hypotheses that consolidated the newly discovered facts and offered explanations for Earth as it existed. Today, Hutton is called the father of modern geology while Werner is hardly known at all outside of Germany. Toward the end of the 18th century, however, Werner's ideas were mostly ascendant.

Werner proposed that Earth was originally an irregular solid body covered completely with a heavily saturated fluid. Over time, solids precipitated from this fluid in a regular succession: first the primitive rocks, such as granite and gneiss; then the transition rocks, such as slates and some limestones; and finally, recent rocks, such as sandstone and other types of limestone. As the fluid lost its chemical content, it gradually became the salty oceans that we know today.

In Werner's theory, which came to be called Neptunism, volcanoes were local phenomena caused by burning coal seams. He did not postulate an inner heat.

The rock basalt became a particular issue between Werner's many followers and other scientists who had identified basalts as essentially cooled lava. These scientists came to be called Vulcansists, after the god who lived in a volcano. Werner explained such basalt structures as the Giant's Causeway in Ireland — giant pillars of basalt like huge, elongated crystals — by saying that a local volcano had melted preexisting basalt, which had then cooled in this formation.

Although Werner's ideas had many attractive features, especially in explaining the sequences of rock strata, they suffered several fatal flaws. One was that Werner never offered an explanation of where the rest of the fluid had gone. Even more alarming was the implication from his theory that all the rock that ever would exist had formed already. It was clear that the continents were gradually being washed into the oceans. If no new rock were formed, the continents would eventually disappear.

James Hutton announced his alternative to Werner's ideas in 1785. He specifically addressed the problem of the continents' wearing away — known as the denudation problem. Hutton gave great importance to the interior heat of Earth, which was well known from mines. As a result, his theory came to be called Plutonism (after the god of the underworld), to contrast with Werner's Neptunism (after the god of the sea). Hutton thought that Earth's heat could cause sediments in the ocean to rise up and become new continents. Today we recognized that this was just as wrong as any of Werner's ideas, but Hutton thought it was testable. In 1787 he identified some rock formations that looked to him like sedimentary rock that had been changed by heat (what we call metamorphic rock today). He believed that his theory had been confirmed.

Since Hutton, too, was wrong, how did he come to be the father of modern geology? He was the first to recognize that changes taking place in the present could account, over a long period of time, for observed features of Earth's crust. Werner's Earth was created and traveled along a foreordained path toward a universal desert. Hutton's Earth always existed and would continue forever to exist very much as it was in 1785, with only the details changed. Of course, neither concept was correct, but Charles Lyell was able to take Hutton's idea of small changes taking place over long periods of time to develop theories that more completely described Earth's history. Finally, nearly two centuries after Werner and Hutton, the plate tectonics theory explained the origin of basalt (from mid-ocean ridges) and recognized the transitory — by geological standards — life of most sediments.

Legendre's extensive work on elliptic integrals and elliptic functions begins. It will continue until 1830, shortly before his death, culminating in the third volume of *Traité des fonctions elliptiques* ("theory of elliptic functions"). Elliptic functions have two periods, similar to trigonometric functions, which have one period. See also 1825 MATH.

Essai sur l'applications de

l'analyse à la probabilité ("essay on the applications of calculus to probability") by Marie-Jean-Antoine, Marquis de Condorcet [b. Ribemont, France, September 17, 1743, d. Bourg-la-Reine, France, April 8, 1794] is an important early work in the science of probability. See also 1713 MATH; 1812 MATH.

♥ Medicine & health

William Withering's *Account*

of the Foxglove reports on his discovery of the use of digitalis, a drug derived from the plant foxglove, in treatment of heart disease. See also 1775 MED.

✿ Physics

Charles Augustin Coulomb discovers that electrically charged bodies discharge spontaneously. In the 20th century it will be found that cosmic radiation is responsi-

ble for this discharge. See also 1912 AST.

Charles Augustin Coulomb makes precise measurements of the forces of attraction and repulsion between charged bodies and between magnetic poles, using a torsion balance, demonstrating conclusively that electric charge and magnetism obey inverse-square laws similar to those of gravity. See also 1760 PHY.



FOXGLOVE, THE SOURCE OF DIGITALIS
The purple foxglove was used by gypsies in England as part of their herbal brew used to treat heart disease. Wealthy physician William Withering learned of the gypsy treatment from a patient and determined that the active ingredient is the poisonous foxglove, beneficial in small doses.

I Tools

Edmund Cartwright invents and patents a power loom. He uses the machine in his own factory in 1787; the machine, however, is imperfect. Power looms will be used widely only after they have been improved in the 19th century. *See also* 1775 TOOL; 1801 TOOL.

↗ Transportation

On January 7 Jean-Pierre Blanchard [b. Les Andelys, France, July 4, 1753, d. Paris, March 7, 1809] and American physician John Jeffries [b. 1745, d. 1819] make the first balloon crossing of the English Channel. *See also* 1784 TRAN; 1794 TRAN.

On June 16 Pilâtre de Rozier and Pierre Romain are killed trying to cross the English Channel by balloon. They are the first casualties of flight. *See also* 1784 TRAN.

The Hudson sloop *Experiment*, captained by Stewart Dean [b. Maryland, July 4, 1748, d. New York City, August 9, 1836], sets sail from New York on December 18 on a voyage to China, becoming the first American ship to make a direct trip to China and back, returning safely in April 1786. *See also* 1843 TRAN.

William Jessop [b. Devonport, England, 1745, d. 1814] develops the first metal rails for cars with flanged wheels to travel upon. *See also* 1797 TRAN.

1786

★ Astronomy

William Herschel publishes his *Catalogue of Nebulas*,

↘ Construction

which eventually will be expanded by Herschel, his son, and J.L.E. Dreyer into the *New General Catalogue*, or NGC, still used by astronomers. *See also* 1888 AST.

■ Construction

Jean-Rodolphe Perronet revives the Italian segmental-arch bridge of the Renaissance in the Pont Sainte-Maxence over the Oise north of Paris. *See also* 1772 CONS; 1791 CONS.

● Earth science

Michel-Gabriel Paccard [b. 1757, d. 1827] and Jacques Balmat [b. 1762, d. 1834] are the first to climb Mont Blanc, on August 8, opening the tops of mountains to human exploration for the first time.

▼ Energy

The first experiments with gas lighting are conducted by the English and Germans. Johann Georg Pickel is the first to experiment with coal gas for lighting in Germany. *See also* 1784 ENER; 1798 ENER.

♥ Medicine & health

Observations on the Cause and Cure of the Tetanus by physician Benjamin Rush [b. Byberry, Pennsylvania, December 24, 1745, d.

Philadelphia, April 19, 1813] suggests that some illnesses may be psychosomatic.

I Tools

Matthew Boulton applies steam power to operate machines that stamp coins. In 1790 he obtains a patent for this technology.



GOLD-LEAF ELECTROSCOPE The amount of static electricity applied to the sphere at the top of the electroscope determines how far the two thin gold leaves suspended from the sphere spread apart, making it possible to measure charge.



Edmund Cartwright

[b. Marnham, Nottingham, England, April 24, 1743, d. Hastings, England, October 30, 1823]

Cartwright was an Anglican churchman who always had been attracted to invention. The Industrial Revolution had been launched in 1733 with inventions that improved or mechanized yarn and cloth production. Cartwright observed the spinning frame used by Richard Arkwright in his factories and vowed to develop a loom for weaving cloth that, like Arkwright's spinning frame, would be water powered. Although Cartwright knew nothing about looms, he spoke with local weavers, who corrected his mistakes and suggested improvements. By 1787 he had developed a water-powered loom that worked well enough for Cartwright to build his own factory. He continued to improve the power loom and eventually converted it from waterpower to steam power. Its design has remained the basis of power looms since. Cartwright developed several other devices that contributed to the ongoing Industrial Revolution. His wool-combing machine of 1789 did the work of 20 persons in preparing sheep's wool for manufacture into yarn. In 1792 he developed a machine to make rope.

Boulton & Watt

Many people have grown up with a mental picture of young James Watt staring at his mother's teakettle, wondering if the pressure of the steam that raised the lid up and down could somehow be harnessed to do work. A truer picture would show the equivalent of a technician at a university who finds that one of his tasks is to repair the university's model of the Newcomen steam engine, a device that had been in use about half a century solely as a form of pump. Watt had been thinking of steam engines before he worked on the Newcomen model, but working on the model crystallized his thoughts. Within a few months he had not only made the repairs, but also developed a series of improvements that would greatly reduce the amount of fuel needed to make the device work. Watt's break came when a business-minded Birmingham, England, manufacturer, Matthew Boulton, picked up a two-thirds share in Watt's invention and also got Parliament in 1769 to grant Watt a patent on the new version of the engine, which Boulton then arranged to have extended through the rest of the 18th century.

The team of Boulton and Watt formed a company — Boulton & Watt — that quickly became one of the driving forces of Britain's Industrial Revolution. Boulton worried about business matters, which he conducted in ways that would make a robber baron envious, and Watt continually improved the steam engine. Even by the time Boulton & Watt was formed, Watt had developed nearly a half-dozen improvements on Newcomen's engine, although it was still basically a pump. Boulton & Watt's first production engines achieved what Watt originally set out to do: to pump water from mines using a quarter of the fuel needed to lift the same amount with a Newcomen engine. Mines in England

quickly replaced their Newcomens with Watts, which paid for themselves even under the severe financial conditions imposed by Boulton, which included a royalty to be paid to Boulton & Watt on the amount of fuel savings obtained by the new engines.

As Boulton moved strongly to protect Watt's earlier patents, Watt himself continued to patent new ideas. The most important of the improvements on the engine itself was the use of steam to push the piston against a vacuum in two directions, rather than just one as in previous engines. He also developed new methods of transmitting power from the pistons to rotary motion and ways to control the engine and to monitor its activity. Although his engines got better and safer, Watt consciously avoided one obvious improvement, the use of high-pressure steam. It is not clear whether he feared that the engines would blow up (as many early high-pressure engines did) or whether he just did not think the improvement was necessary.

Around the time Watt turned 65, his basic steam engine patents ran out. Watt and Boulton retired from Boulton & Watt, although their sons continued the famous partnership. Watt lived nearly 20 years more. While Boulton eventually went back into business, Watt stayed clear of steam engines; however, he could not resist inventing. Boulton's firm, before the advent of the Watt engine, had engaged in manufacturing devices for copying, and Watt worked on improvements along those lines in his advanced years. This was not a new interest, as his first copying patent, for production of documents that could be mechanically reproduced, had been filed while Watt worried over steam engine development.

Watt's last inventions were devoted to the problem of copying sculpture, which he succeeded in doing as he had succeeded in every other inventive endeavor he attempted.

English physicist Abraham Bennet [b. 1750, d. 1799] invents the gold-leaf electro-scope. It is an instrument that indicates the presence of electric charge by the mutual repulsion of two thin gold leaves. *See also* 1766 TOOL; 1820 TOOL.

1787

★ Astronomy

Pierre-Simon Laplace's *Mémoire sur les inégalités séculaires des planètes et des satellites* ("note on the long-term irregularities of planets

and satellites") is an early work leading to his mammoth *Mécanique céleste*. *See also* 1799 AST.

William Herschel discovers Titania and Oberon, moons of Uranus. *See also* 1684 AST; 1789 AST.

Chemistry

Claude Louis Berthollet [b. Talloire, Haute Savoie, France, December 9, 1748, d. Arcueil, near Paris, November 6, 1822] discovers the composition of ammonia, prussic acid, and hydrogen sulfide. *See also* 1789 CHEM.

The first of four volumes of *Méthode d'une nomenclature chimique* ("method of chemical nomenclature"), written by Guyton de Morveau, with Lavoisier, Berthollet, and Fourcroy, presents a system for naming chemicals based on scientific principles. *See also* 1789 CHEM.

Construction

Thomas Paine [b. Thetford, England, 1737, d. New York City, June 8, 1809], the American patriot writer, brings a model of an iron bridge he has designed to England. The

bridge had originally been planned for the Schuylkill near Philadelphia, Pennsylvania, but is rethought for the river Wear at Sunderland, England. *See also* 1779 CONS.

Energy

Edward Nairne [b. Sandwich, England, 1726, d. London, September 1, 1806] builds an electrostatic generator consisting of a glass cylinder mounted on glass insulators; the device can supply either positive or negative electricity. *See also* 1783 ENER; 1789 ENER.

✿ Physics

Jacques-Alexandre Charles shows that different gases expand by the same amount for a given rise in temperature (Charles's law). *See also* 1662 CHEM; 1801 CHEM.

Ernst Florens Friedrich Chladni [b. Wittenberg, (Germany), November 30, 1756, d. Breslau, Silesia (Poland), April 3, 1827] experiments with sound patterns on vibrating plates. *See also* 1809 PHY.

→ Transportation

The first steamboat in the Americas is demonstrated by John Fitch [b. East Windsor, Connecticut, January 21, 1743, d. Bardstown, Kentucky, July 2, 1798] to the Constitutional Convention on the Delaware River at Philadelphia. This steam engine drives paddles rather than the more familiar wheel. By 1790 one of Fitch's steamboats is in regular service for several weeks during the summer, but it is a commercial failure. *See also* 1783 TRAN.

John Wilkinson builds the first cast-iron barge for use in carrying armaments down the Severn River from his factory.

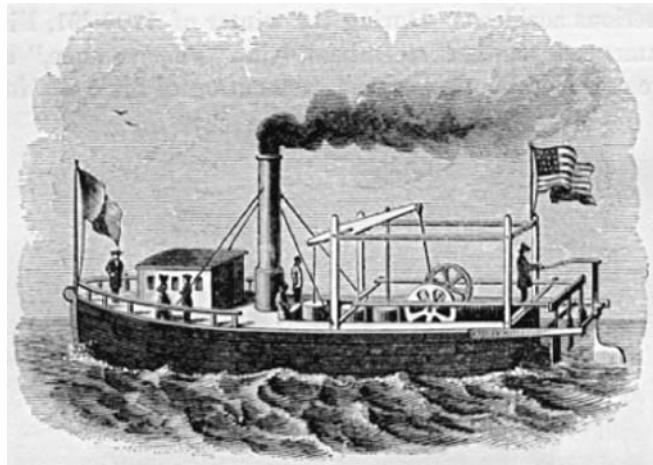
1788

□ Chemistry

Physician Sir Charles Blagden [b. Gloucestershire, England, April 17, 1748, d. 1820] discovers that the freezing point of a solution becomes lower in proportion to the concentration of material dissolved.

□ Communication

Abraham Rees completes a project combining the supplement with the original vol-



FITCH'S SECOND STEAMBOAT John Fitch built a series of steamboats. While the paddles of the first were at the side of the boat and operated like the paddles of a canoe, this second ship had the paddles at the back. Note that there was no need to change the reciprocating action of the steam engine to rotary. Later, and more successful, steamboats used paddle wheels instead of back-and-forth paddles.

umes of Chambers's *Cyclopaedia* and also adding more than 4000 new entries. The resulting book amounts to 418 short volumes in a cheap format that will be published alphabetically over a ten-year period. *See also* 1753 COMM.

■ Construction

Sir John Soane [b. Whitchurch, England, September 10, 1753, d. London, January 20, 1837] designs and rebuilds the Bank of England building, the first Greek revival building in England, setting an important style for both Britain and North America. Soane's design is closely copied from a round temple at Tivoli (near Rome), itself a Greek imitation by Roman architects. Continental architects at this time also build classical revival buildings. *See also* 1819 CONS.

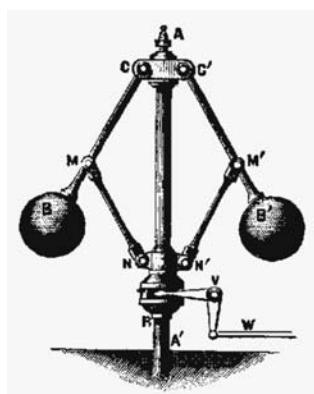
♥ Medicine & health

French surgeon Pierre-Joseph

Principle of Least Action: the motion of a system between two points takes place so that a quantity called *action* (the product of force, distance, and time) is minimized. *See also* 1744 PHY.

I Tools

James Watt adapts the centrifugal governor for controlling the speed of steam engines. The device, already in use in flour mills, consists of two balls mounted on two arms and is set in rotation by the engine. When the speed increases, the balls fly outward because of centrifugal force and close a butterfly valve that controls the admission of steam to the cylinder. *See also* 1783 ENER; 1790 ENER.



GOVERNOR FOR STEAM ENGINE As the motor turns, it also rotates the vertical axis of the governor; centrifugal force then causes the two heavy balls to move apart. The farther apart the balls move, the more the mechanism closes a valve on the steam engine that reduces the flow of steam and slows the rotation, which then allows the balls to fall toward each other, opening the valve again. In practice, the effect is to keep the engine from going beyond a certain speed.

1789

★ Astronomy

William Herschel completes his great reflecting telescope, with a mirror 124.5 cm (49 in.) in diameter and a focal length of 12.2 m (40 ft). Although a technological marvel for the age, it is too cumbersome to be used frequently. With it, however, Herschel discovers Saturn's moon, Enceladus. *See also* 1787 AST; 1847 AST.

☒ Biology

Antoine Laurent de Jussieu's *Genera planarum* ("types of plants") is a classification of plants into families on bases that are still accepted today (for example, grasses, lilies, and palms). *See also* 1737 BIO; 1795 BIO.

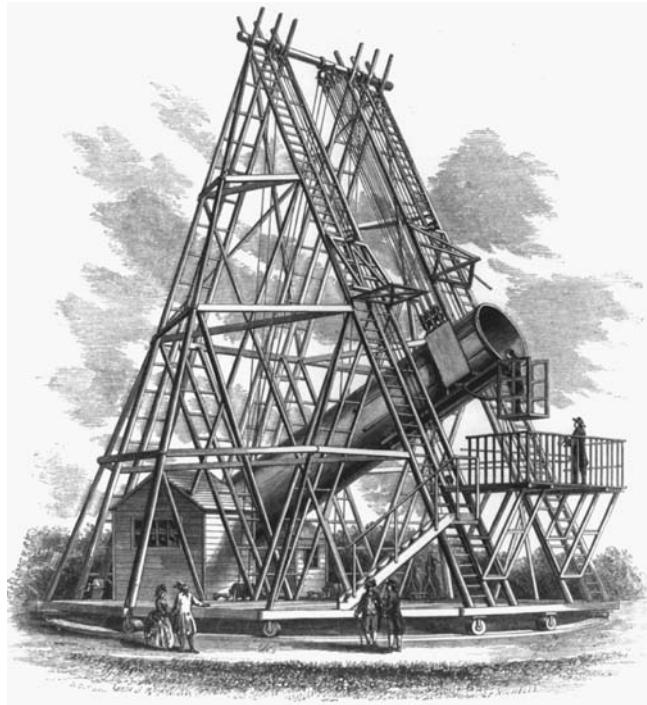
Johann Wolfgang Goethe's *Versuch, die Metamorphose der Pflanzen zu erklären* ("attempt to explain changes in plants") claims incorrectly that all plant structures are modified leaves, but clearly espouses evolution. *See also* 1751 BIO.

☒ Chemistry

Lavoisier publishes the textbook *Traité élémentaire de chimie* ("elementary treatise on chemistry"), which firmly establishes the oxygen theory and the new chemical nomenclature. It also states the law of conservation of mass. *See also* 1782 CHEM; 1842 ENER.

Lavoisier publishes a "table of thirty-one chemical elements," to which he adds light and heat, which he believes to be material, but without mass. *See also* 1787 CHEM.

Claude Louis Berthollet introduces the use of chlorine for



HERSCHEL'S GIANT REFLECTOR In the 19th century as today, large telescopes needed scaffolding to hold them and machinery to aim them, but the familiar dome to cover the works had not been added to the observatory. Note that the observer, presumably Herschel, is looking down at the mirror from the end pointed at the sky. Two assistants on the ground were needed to point the tube where Herschel indicated.

chemical bleaching and markets a solution containing it under the name *bleach* after the town where it is manufactured. *See also* 1787 CHEM; 1799 CHEM.

Martin Heinrich Klaproth [b. Wernigerode, (Germany), December 1, 1743, d. Berlin, January 1, 1817] discovers uranium (U) and zirconium (Zr). *See also* 1824 CHEM.

☒ Communication

Ernst Chladni invents the euphonium, a musical instrument in the tuba family.

☒ Ecology & the environment

The Natural History and Antiquities of Selborne, a series of

notes about animal and plant life about the town of Selborne, England, written by clergyman Gilbert White [b. Selborne, 1720, d. June 26, 1793] is the first recognizable work of ecology. It goes through about 200 different editions, making it among the most frequently reprinted titles in English.

☒ Energy

Abraham Bennet invents a simple electric induction machine. *See also* 1787 ENER.

The first cotton factory driven by steam is opened in Manchester, England. *See also* 1767 ENER; 1801 ENER.

☒ Medicine & health

British physician Michael

Underwood provides the first clinical description of a disease that he calls "a debility of the lower extremities." Today we recognize the disease as poliomyelitis, or polio.

I Tools

Edmund Cartwright develops a wool-combing machine that replaces more than 20 hand-combers. *See also* 1748 TOOL; 1850 TOOL.

→ Transportation

The Sapperton Tunnel in England, over 3 km (2 mi) long, links the highest navigable part of the Thames River to the Stroudwater Canal. *See also* 1777 TRAN; 1805 TRAN.

Oliver Evans takes out the first U.S. patent for a steam-propelled land vehicle. *See also* 1784 TRAN; 1801 TRAN.

1790

◀ Anthropology

Archaeologist John Frere discovers flint tools at Hoxne in Suffolk that he believes were made by prehistoric humans, but few agree with him. Among the tools are typical Acheulean hand axes. It is not until 1846 that Boucher de Crévecoeur de Perthes [b. Rethel, France, September 10, 1788, d. Abbeville, France, August 5, 1868] is able to convince other scientists that humans once used flint tools. *See also* 350,000 BCE TOOL; 1863 ARCH.

Johann Blumenbach's *Collectionis suaे craniorum diversarum gentium illustratae decades* ("collections of diverse skulls") gives descriptions of 60 human crania. *See also* 1776 ANTH; 1795 ANTH.

★ Astronomy

William Herschel discovers planetary nebulae, recognized today as spherical clouds of gas as much as a light-year across that has been emitted by a hot star. Energy from the star makes the gas glow. Herschel names them “planetary” because they show a disk (like a planet in the solar system), but he recognizes they are gas clouds — the first recognition that some glowing patches among the stars consist of gases. *See also* 1811 AST.

Communication

On March 30 Charles Maurice de Tallyrand, then bishop of Autun, proposes the first ver-

sion of a metric system of measurement to the French National Assembly, but details are still to be worked out. It is to be based on the length of a pendulum that swings once per second. *See also* 1758 COMM; 1793 COMM.

The U.S. Congress introduces its first patent law, pursuant to Article I Section 8 of the Constitution, which had become effective in 1789. The first U.S. patent is granted to Samuel Hopkins of Philadelphia for a process for making potash from wood ashes. *See also* 1623 COMM.

▼ Energy

James Watt builds a pressure gauge, or “indicator,” that displays the pressure inside the cylinder of a steam engine. *See also* 1796 ENER.

■ Food & agriculture

Dahlias, native to Mexico, are first imported into England. *See also* 1753 FOOD.

◊ Materials

The first rolling mill driven by steam is opened in England. *See also* 1754 MATR; 1795 MATR.

▼ Medicine & health

George Washington’s dentist, John Greenwood [b. Boston,

May 17, 1760, d. New York, November 16, 1819], invents the dental drill. *See also* 1771 MED.

American dentist Josiah Flagg [b. Boston, c. 1763, d. 1816] invents the dentist’s chair. *See also* 1832 MED.

Porcelain begins to be used as a base plate material for dentures, replacing ivory, bone, and gold, all of which are hard to fit. *See also* 1756 MED; 1860 MED.

⊗ Physics

Friedrich Gren [b. 1760, d. 1798] founds the *Journal der Physik*, today known as the *Annalen der Physik*.

A continuing search for fiber

Although Western tradition ranks clothing among the basic needs along with food and shelter, the members of some human societies in the recent past wore no clothing, and many societies today wear very little. Climate is not the deciding factor for nakedness, as societies known to use the least amount of clothing, the Fuegan and Tasmanian of 200 years ago, lived on islands with notoriously bad weather. In Europe, however, clothing is known from very early times. Small statues depict clothing as early as 15,000 BCE. This clothing is thought to be of animal skins, but linen cloth made by weaving existed at least as early as 6000 BCE. In any case, animal skins are not the right shape or size for clothing and need to be sewn together with fiber of some sort. While thin strips of skin have been used as fibers, the Ice Man of 3300 BCE used animal sinews in some places and grass in others.

Although the earliest recorded evidence of the use of fiber involves flax — linen is fiber from the flax plant — ambiguous evidence suggests that wool from sheep or goats was employed for cloth by that time as well. Sheep and goats were among the first domesticated animals; in the New World, llamas and alpacas, which also produce wool, were also domesticated early.

In warmer climates of both the Old and New worlds, cotton became the most common plant fiber from early times. By the 18th century CE, cotton was shipped all over the world. Introduc-

tion of new ways of processing cotton was a hallmark of the Industrial Revolution.

Humans are not the only animals to use fiber. Birds have long used animal hair and plant fibers for nest building. They also anticipated humans in the discovery of the utility of silk, a chemical fiber produced by spiders and caterpillars. Most birds prefer spider silk, some of which forms a micro-Velcro and some of which has adhesives attached. People in China discovered that the caterpillar of the silkworm moth produces the longest silk fibers in nature, some 900 m (3000 ft) long. Shiny silk was seen from the first as superior to animal hair or plant fibers. During the Chinese’s virtual monopoly of hundreds of years, trade in silk became the strand that held eastern Asia to the West along the famous Silk Road.

Silk begins as a liquid that is extruded through a tiny opening; it hardens into a solid in the air. As early as the 17th century, inventors recognized that this process could be imitated by a machine if the right liquid were found. Some early attempts used gums or other natural plant products. Chemists in the 19th century perceived that cellulose from the breakdown of wood or some variation on it would do the trick. At least a half dozen different versions of such artificial silks emerged, the best of which we now call rayon. In the 20th century, the same idea was used with a different class of chemicals, the polymers. In bulk, the polymers are plastics, but as fibers they are nylon, Dacron, and polyester. For many purposes, the artificial fibers are better (wrinkle-free cloth is often cited as the greatest boon), but natural fibers continue to excel for others.

I Tools

William Nicholson [b. London, 1753, d. London, May 21, 1815] patents a cylinder printing press. *See also* 1783 COMM.

→ Transportation

Comte Mede de Sivrac in France builds a bicycle propelled by the feet, called a *célerifère* (roughly “quick strike”), essentially an adult version of the 18th-century toy called the hobby horse. Only a court plaything at first, an improved version becomes popular in Paris around 1816. *See also* 1816 TRAN.

John Fitch uses his steamboat on the Delaware River to establish commercial service between Philadelphia, Pennsylvania, and Burlington, New Jersey, about 30 km (20 mi) north; the boat, which travels about 6.4 km (4 mi) per hour, is not a financial success, in part because it is out of service much of the time. *See also* 1787 TRAN; 1797 TRAN.

1791

Chemistry

Jeremias Benjamin Richter [b. Hirschberg, (Germany), March 10, 1762, d. Berlin, April 4, 1807] establishes the principle of fixed chemical reactions called stoichiometry. For example, acids and bases in neutralizing each other always do so in the same proportion.

William Gregor [b. Trewarthenick, England, December 25, 1761, d. Creed, England, July 11, 1817] discovers titanium (Ti).

Richard Kirwan [b. Cloughnallmore, Ireland, August 1, 1733, d. Dublin, Ireland, June 22, 1812], one of the last defenders of the phlogiston

theory of fire, gives up in the face of overwhelming evidence that the theory is wrong. *See also* 1783 CHEM.

■ Construction

Jean-Rodolphe Perronet builds the graceful Pont de la Concorde bridge in Paris. *See also* 1786 CONS.

↗ Energy

John Barber [b. Nottinghamshire, England, 1734, d. c. 1800] patents a simple gas turbine: air, compressed by heating, is directed at a paddle wheel. Its efficiency is very low. *See also* 1827 ENER.

♥ Medicine & health

Traité medico-philosophique sur l'aliénation mentale (“medico-philosophical treatises on mental derangement”) by physician Philippe Pinel [b. Tarn, France, April 20, 1745, d. Paris, October 26, 1826] advocates a more humane treatment of persons suffering mental illness. *See also* 1777 MED; 1808 MED.

✿ Physics

Pierre Prévost [b. Geneva, Switzerland, March 3, 1751, d. Geneva, April 8, 1839] develops his theory of exchanges of radiation of heat. He correctly shows that cold is merely the absence of heat and that all bodies continually radiate heat. Bodies that seem not to radiate heat are in heat equilibrium with their environment. *See also* 1744 PHY; 1798 PHY.

Luigi Galvani announces that electricity applied to severed frogs’ legs causes them to twitch and that frogs’ legs twitch in the presence of two different metals with no electric current present. The latter discovery eventually leads to

Alessandro Volta’s developing the electric battery. *See also* 1771 PHY; 1800 ENER.

1792

Archaeology

Workers excavating drains in the main square of Mexico City find the Aztec calendar stone and a large statue of the Aztec goddess Coatlicue. Church authorities have the stones reburied lest they remind natives of their pagan past. *See also* 1802 ARCH.

▷ Chemistry

The world’s first chemical society, the Chemical Society of Philadelphia, is founded in Pennsylvania. *See also* 1876 CHEM.

◁ Communication

The optical semaphore signaling system invented by Claude Chappe [b. Brulon, France, December 25, 1763, d. Paris, January 23, 1805] and his brother Ignace [b. 1760, d. 1829] to send each other messages while at school is officially adopted by the French legislature. *See also* 1684 COMM; 1793 COMM.

■ Construction

Timothy Palmer builds the first modern truss bridge; made from timber, it spans the Merrimack River near Merrimack, New Hampshire. *See also* 1570 CONS; 1805 CONS.

● Earth science

Jean-Baptiste Delambre [b. Amiens, France, September 19, 1749, d. Paris, August 19, 1822] and Pierre François Méchain [b. Laon, France, August 16,

1744, d. Spain, September 20, 1804] begin their measurement of the arc of the meridian of longitude from Dunkirk to Barcelona, leading to the establishment of a uniform system of measures. *See also* 1671 EAR; 1841 EAR.

↗ Energy

Inventor William Murdoch introduces coal-gas lighting to England, using it to light his home in Redruth, Cornwall. *See also* 1786 ENER; 1799 ENER.

I Tools

Edmund Cartwright invents a machine for making rope (a corderlier). *See also* 15,000 BCE MATR.

John Prince is the first to build a microscope in the United States. *See also* 1742 TOOL.

Evidence suggests that manual operations are being timed with a stop watch at the Derby china works in England with an eye toward speeding up production.

1793

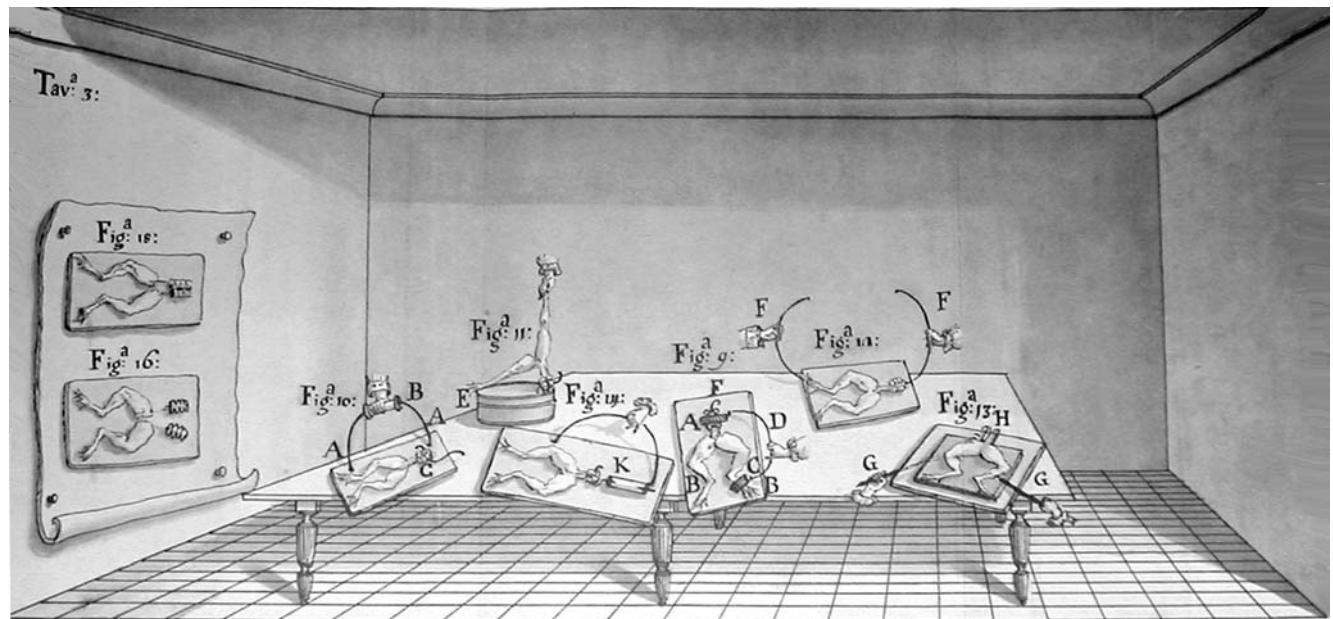
Biology

German botanist Christian Konrad Sprengel [b. Spandau, (Germany), September 22, 1750, d. Berlin, April 7, 1816] publishes his findings on plant fertilization by insects and by wind. *See also* 1761 BIO.

◁ Communication

In August the revolutionary government in France abolishes the Académie des Sciences and its universities. *See also* 1795 COMM.

Louis-Etienne Herhan, Firmin Didot [b. Paris, April 14, 1764, d. Mesnil-sur-l’Estree, France,



GALVANI'S FROG EXPERIMENTS Galvani became convinced from a series of experiments, initially conducted on frog's legs, but later with mammals and birds, that animal tissues contain electricity. The key experiment is shown in Figure 11, second from the left on the table. A hand holds one leg while the other leg, pierced with an iron hook, is lowered so the hook touches a silver box. The leg muscles contract and lift the hook off the box. After a moment, the muscles slowly relax, and the hook once again touches the box, causing the leg to lift again, an action that repeats over and over.

1836], and Nicolas-Marie Gatteaux [b. 1751, d. 1832] develop between 1793 and 1797 a method for pressing the plates used in stereotype printing. *See also* 1725 COMM.

The first official semaphore-telegram in history is sent on August 15 to announce the French victory in the war with Austria via Claude Chappe's network of semaphore stations. Chappe coins the term "telegraph" for his system of transmitting messages. *See also* 1792 COMM.

A commission including Lagrange, Laplace, and Lavoisier is appointed to draw a new system of weights and measures. The commission devises the metric system, which is adopted in 1795. *See also* 1790 COMM.

Earth science

Meteorological Observations and Essays by John Dalton reflects his weather observations since 1787, a practice he will continue for the rest of his life.

Jean-Baptiste Lamarck argues that fossils are the remains of

organisms that once were living. *See also* 1740 EAR; 1815 EAR.

Food & agriculture

In April Eli Whitney [b. Westboro, Massachusetts, December 8, 1765, d. New Haven, Connecticut, January 8, 1825] invents the cotton gin. It con-

sists of a hand-cranked wooden cylinder with spikes that pass through the bars of a grid. Cotton fibers pass through the grid while the seeds are expelled. The gin (short for engine) could increase the output of a worker fifty-fold. *See also* 1818 TOOL.



John Dalton

[b. Eaglesfield, England, c. September 6, 1766, d. Manchester, England, July 27, 1844]

Dalton is best known for his 1803 revival on a scientific basis of the ancient Greek idea that all materials are formed from tiny particles (atoms). In part, Dalton had prepared for this idea with his development of two gas laws — a rule for the pressure of a mixture of gases (the law of partial pressures) and one for the way volume changes with temperature (called Charles's law, although first stated by Dalton). Dalton also developed the theory of red-green colorblindness (he himself was colorblind); hence colorblindness is called daltonism. Dalton was the first to demonstrate that water in springs originates as precipitation.



Thomas Young

[b. Milverton, Somerset, England, June 13, 1773, d. London, May 10, 1829]

Young is famous for his work on light and vision. He showed that changes in curvature of the eye's lens focus light, found the cause of astigmatism, and proposed the correct three-color explanation of color vision. Young's experiments with interference of light waves and diffraction of shadows established the wave nature of light. Young was the first to recognize that light travels as transverse waves. In other areas, Young was the first to define energy in the modern sense. He improved on Hooke's law by providing a measure — Young's modulus — showing the constant of proportionality between force and stretching for different substances. He even helped establish the basis for translation of Egyptian hieroglyphics.

In Britain the Board of Agriculture is formed to oversee the various "improvement societies" that have been formed to promote the education of British farmers in better agricultural practices.

♥ Medicine & health

John Hunter is the first to ligate the femoral artery for the treatment of aneurysm.

I Tools

Thomas Young is the first to apply engineering concepts to a biological problem, how the eye focuses.

Hannah Slater, wife of Samuel Slater (a pioneer in converting English spinning technique to American manufacture), is the first woman to whom a patent is granted in the United States. She invents a new way to spin cotton sewing thread. *See also* 1779 TOOL; 1828 TOOL.

→ Transportation

The French Canal du Centre joins Digoin on the Loire River (which empties into the English Channel) with Chalon-sur-Saône on the Saône River (which flows into the Mediterranean). *See also* 1785 TRAN.

Jean-Pierre Blanchard makes the first successful parachute jump from a balloon. *See also* 1783 TRAN.

1794

★ Astronomy

Ernst Chladni argues that meteors are extraterrestrial based on his analysis of the type of iron found in two meteorites that had fallen separately at a great distance from each other. Most scientists of the time do not accept his conclusion, believing that meteorites are caused by lightning striking soil that has been lifted into the sky by storms (hence a common name of the time for a meteorite, "thunder stone"). *See also* 1795 ast

☒ Biology

John Dalton's *Extraordinary Facts Relating to the Vision of Colors* gives the earliest account of colorblindness, which he refers to as daltonism, since he is afflicted with the condition.

Zoonomia by physician Eras-

mus Darwin [b. Elston Hall, Nottinghamshire, England, December 12, 1731, d. Bread-sall Priory, near Derby, England, April 18, 1802] contains his ideas about evolution, which are Lamarckian in that they assume the environment has a direct influence on organisms, causing permanent changes in the germ line (a belief now known to be incorrect). Erasmus Darwin is the grandfather of the author of *Origin of Species*. *See also* 1801 BIO.

▷ Chemistry

Johan Gadolin [b. Åbo, Finland, June 5, 1760, d. Wirmo, Finland, August 15, 1852] discovers yttrium (Y) in a Swedish mineral deposit. The new element is not completely separated from other rare earths and other elements, however, until the 1840s, when Carl Gustav Mosander [b. Kalmar, Sweden, September 10, 1797, d. Angsholm,

Sweden, October 15, 1858] breaks apart many of the rare earths.

Lavoisier is executed by the radical faction of the French Revolution.

↳ Communication

The Conservatoire National des Arts et Métiers ("national conservatory of arts and crafts") in Paris is founded. The institution is a museum of science and technology in which a model of every new invention is to be deposited.

The Ecole Polytechnique opens in Paris in December. It will produce the scientific elite of France during the early years of the 19th century. *See also* 1751 COMM.

⊕ Earth science

William Smith publishes the first large-scale geological map of England. *See also* 1778 EAR; 1811 EAR.



William Smith

[b. Churchill, England, March 23, 1796, d. Northampton, England, August 28, 1839]

In a time of considerable canal building, Smith specialized in surveying canal routes. In the process he discovered that fossils can be used to recognize strata found many miles apart. He proposed the principle of superimposition, stating that lower strata are older than those above them. He published the first geological maps of Great Britain, starting in 1815.

An American genius

The realization that Eli Whitney was among the most important Americans at the start of the republic has come only gradually to historians, even historians of technology. Today it is clear that his most famous invention, the cotton gin, saved the United States South economically while encouraging the slave and plantation systems that ultimately led to the Civil War. Yet it is likely that the gin, a simple device that Whitney made in a few days, would have been invented by someone else as well. Whitney's true worth came from the invention of the "American system" of manufacture and the creation of specialized tools. He also was the first American to utilize standardized parts, an idea probably originally owed to Leblanc, a French arms manufacturer. Whitney's development of cost accounting and establishment of stable government contracts originated methods still used for successful manufacture of all sorts.

Whitney showed inventiveness and intelligence from an early age, taking apart and reassembling his father's watch, for example. He used these skills to put himself through high school and Yale University. On graduation from Yale, deeply in debt (as circumstances were to keep him for most of his life), he had the pivotal encounter of his life. Taking a job as a tutor in far-off South Carolina, he arranged to travel with another young man, Phineas Miller, the manager of the considerable estate of the widow of General Nathanael Greene. All the evidence suggests that Whitney fell hopelessly in love with Catherine Greene, and remained so until her death. (Catherine, however, eventually married Miller.) At first, Whitney lingered at the Greene estate instead of taking his tutoring assignment. While there he learned of the problem of separating seeds from cotton fiber. Mrs. Greene said she was sure that Eli was clever enough to solve it, which turned out to be the case. Whitney

formed a partnership with Miller to promote his invention, the cotton gin.

Miller, however, through bad policy, came close to wrecking the business in a variety of ways. The gin was pirated, lawsuits were fought badly, and Miller lost money on land speculation as well. In the final analysis, Whitney never made any significant amount of money on his ubiquitous gin.

Nevertheless, he had access to enough capital to enter another business, this time without Miller. Learning that the U.S. army needed muskets, he invented in 1798 the "American system" of using powered, specially designed machines to make interchangeable parts. The then-standard manufacturing system used one skilled maker to produce all the parts for an individual musket by hand. Whitney needed several years to design the machines, build the plant, train the workers, and produce the muskets. Although he continued to be in debt much of this time, ultimately he demonstrated that his method was far superior.

Even though the strength of Whitney's system seems obvious today, it was not so at first to his contemporaries. He was nine years late in fulfilling his first major government contract.

Aside from the manufacturing system, the most important of Whitney's inventions was the milling machine, a modified lathe that turns out irregularly shaped parts. Without the milling machine, it is difficult to see how standardized parts could ever have been invented. Whitney also invented the tumbler mill near the end of his life, although he was too ill to make anything more than drawings and plans.

Whitney's illness, which resulted in his death before the age of 60, was an enlargement of the prostate. He invented or reinvented the flexible catheter to relieve himself and probably thus gave himself another couple of years of life as well as some cessation of pain. That other American genius, Benjamin Franklin, may have made the same invention when faced with a similar problem in 1784.

Σ Mathematics

Adrien-Marie Legendre's *Éléments de géométrie* ("elements of geometry") is a simplification and rearrangement of Euclid that becomes the basic geometry textbook in France and the United States for most of the 19th century. *See also* 1733 MATH; 1899 MATH.

⌘ Physics

Alessandro Volta demonstrates that the electric force observed by Luigi Galvani is

not connected with living creatures, but can be obtained whenever two different metals are placed in a conducting fluid. *See also* 1791 PHY; 1800 ENER.

I Tools

Daniel Rutherford designs the first maximum-minimum thermometer. *See also* 1742 TOOL.

↗ Transportation

On June 2 Jean Marie-Joseph

Coutelle [b. 1748, d. 1835] and an ordinance officer of the French army rise above the battlefield in the balloon *Entreprenant* to conduct the first aerial surveillance. As a result of this and later missions, the French win the battle of Fleurus. *See also* 1785 TRAN; 1858 TRAN.

One of the first U.S. canals, the Dismal Swamp Canal from Chesapeake Bay to Albemarle Sound, is completed;

work on it started in 1787. *See also* 1793 TRAN.

1795

◀ Anthropology

In the third edition of *De generis humani varietate nativa liber* ("on the natural varieties of mankind"), Johann Blumenbach proposes that there is a fifth race, the Malayan. *See also* 1776 ANTH; 1819 ANTH.

★ Astronomy

Edward Pigott discovers the variable stars R Coronae Borealis and R Scuti. Pigott later will try to explain variables in terms of rotating bodies that have light and dark patches. *See also* 1784 AST.

On December 13 an iron meteorite falls on a cottage. Analysis shows that it has the same type of iron composition as the two investigated by Ernst Chladni. *See also* 1794 AST.

☒ Biology

Georges Cuvier at the Museum of Natural History in Paris develops a method of classifying of mammals. *See also* 1789 BIO.



Georges Léopold Chrétien Frédéric Dagobert Cuvier

[b. Montbéliard, France, August 23, 1769, d. Paris, May 13, 1832]

Cuvier played a major role in establishing the fields of comparative anatomy and paleontology. He made the first important studies of fossils, applying his knowledge of comparative anatomy to the reconstruction of skeletons of extinct animals found in rocks quarried near Paris. Cuvier noted the similarity of fossil and living forms but did not believe in evolution. His theory of catastrophism proposed that a succession of disasters through time killed all life, after which new life forms were created.

⌚ Communication

France adopts the metric system as its official system of measurement. *See also* 1793 COMM.

N.J. Conté develops the method of making pencil leads by mixing ground graphite into clay, forming the mixture into thin rods, and firing it. Essentially, this method has been used ever since. *See also* 1760 COMM; 1822 COMM.

The Institut National des Sciences et des Arts in Paris is established to replace abolished academies in France. Among its 48 scholars are Lagrange and Laplace, but not Legendre, although Legendre is quickly elected to membership by his colleagues. *See also* 1793 COMM.

☒ Earth science

Georges Cuvier identifies bones found between 1766 and 1780 in a quarry near the Meuse River in the Netherlands as belonging to a giant, prehistoric reptile, which we know now as the *Mosasaur*, a 14-m-long sea reptile. *See also* 1780 EAR; 1812 EAR.

🍴 Food & agriculture

Napoleon offers a prize for a practical method of preserving foods, which is eventually won by Nicolas Appert. He introduces a sterilization process for food by bottling or canning, heating, and sealing in 1804 and wins the prize in 1809. *See also* 1765 FOOD; 1804 FOOD.

The average sheep sold for mutton in London's Smithfield Market weighs more than double the typical 18-kg (40-lb) sheep of 1710 as a result of selective breeding for weight.



Nicolas François Appert

[b. Châons-sur-Marne, France, October 23, 1752, d. Massy, near Paris, June 3, 1841]

In 1795 the French government offered a prize of 12,000 francs to the person who could develop an effective method of preserving food. Appert's solution was to put food in bottles, as is done with wine. He experimented with various techniques before reaching a conclusion: food could be preserved if it were heated to boiling and sealed in airtight glass jars. In 1809 Emperor Napoleon Bonaparte — grateful to have a safe method of preserving food for troops in foreign lands — personally awarded Appert the prize of 12,000 francs.

British inventor Peter Durand decided that Appert's invention would be more practical if the container were metal rather than breakable glass. In 1810 he received a patent for creating a cylindrical canister made of iron coated with tin.

❖ Materials

Rolled iron plate is available commercially. *See also* 1790 MATR.

♥ Medicine & health

Morbid Anatomy of Some of the Most Important Parts of the Human Body by anatomist Matthew Baillie [b. Shotts, Lanarkshire, Scotland, October 27, 1761, d. September 23, 1823] is the first work to treat pathology as a subject in itself. *See also* 1707 MED.

Physician Sir Gilbert Blane [b.

Blanefield, Scotland, August 29, 1749, d. London, June 26, 1834] makes the use of lime juice to prevent scurvy mandatory in the British navy, based on the proposal of James Lind that citrus fruit be used against the disease that attacks people on long voyages. This is the origin of the nickname "limey" for the British sailor. *See also* 1753 MED.

I Tools

Joseph Bramah invents the hydraulic press, which consists of two pistons, one with a wide diameter and one narrow, both filled with a fluid and connected. When pressure is applied to the small piston, the large piston exerts a greater force. *See also* 1663 PHY.

✈ Transportation

Samuel Morey [b. Hebron, Connecticut, October 23, 1762, d. Fairlee, Vermont, April 17, 1843] patents the use of a steam engine to propel a boat. *See also* 1790 TRAN; 1797 TRAN.

1796

★ Astronomy

Pierre-Simon Laplace's *Exposition du système du monde* ("explanation of the system of the world") states his "nebular hypothesis": the solar system evolved from a condensing cloud of gas. In modern form, this idea is still accepted by most astronomers. *See also* 1755 AST.

☒ Chemistry

Johann Tobias Lowitz [b. Göttingen, Germany, April 25, 1757, d. St. Petersburg, Russia,



(Johann) Karl Friedrich Gauss

[b. Braunschweig, Germany, April 30, 1777, d. Göttingen, Germany, February 23 1855]

Gauss is ranked with Archimedes and Newton as the greatest of mathematicians. At age 19 he constructed a regular polygon with 17 sides, the first major new construction since Greek times. In 1799 he provided the first proof that all equations formed by setting a polynomial equal to zero have a solution, the fundamental theorem of algebra. In 1801 he completely restructured number theory. An interest in surveying led to his 1827 theory that mathematically describes properties of surfaces. The asteroid Ceres was discovered in 1801, but astronomers soon lost the location of the dim body. Gauss invented a way to calculate the path of a planet from a few observations. When Ceres was found exactly where he predicted, his fame was ensured.

Gauss was the first to establish a non-Euclidean geometry but he did not publish it. Other mathematicians soon rediscovered it. Gauss similarly discovered much of advanced calculus but failed to publish his results. It is said that his discoveries would have advanced mathematics by 50 years if announced when made. Gauss also studied Earth's magnetic field. He and a collaborator built a working telegraph more than a decade earlier than the 1843 system of Samuel F.B. Morse.

December 7, 1804] prepares pure ethyl alcohol.

Communication

The German encyclopedia now known as *Der Grosse Brockhaus* publishes the first volume of its first edition under the title *Conversations-Lexicon* and the editorship of Gotthelf Renatus Löbel [b. Thalwitz, Saxony (Germany), April 1, 1767, d. February 14, 1799]. See also 1771 COMM; 1808 COMM.

Francisco Salva of the Academy of Science in Barcelona installs an electric telegraph linking Madrid to Aranjuez, a distance of 50 km (30 mi). The link consists of 44 wires allowing the apparatus to transmit 22 characters in each direction. Signals are generated by electrostatic machines and detected by people holding the ends of the wires in their hands; they feel a tingle or slight shock. Later Salva uses the occurrence of sparks to detect signals. See also 1774 COMM; 1809 COMM.

Construction

British engineer Rowland Burdon [b. 1756, d. 1838] builds a cast-iron bridge over the river Wear, starting in 1795. This bridge has a much

greater span than Darby's Iron Bridge over the Severn because of a flatter arch and lighter, more open construction. Some attribute its basic design to Thomas Paine's model iron bridge. See also 1787 CONS.

Energy

John Southern improves the "indicator" developed by James Watt. A pencil is attached to a pressure gauge connected to the cylinder of a steam engine; it records the variations of pressure on a tablet that follows the motion of the piston rod. The pencil describes a closed curve whose area is a measure of the power produced by the machine. See also 1790 ENER.

Mathematics

On March 30 Karl Friedrich

Gauss discovers how to construct a regular polygon of 17 sides using just a compass and straightedge. This discovery convinces Gauss to become a mathematician instead of a linguist.

Gauss succeeds in proving the law of quadratic reciprocity after a year-long effort. He had discovered this theorem dealing with prime numbers independently of Euler, who stated it without proof in 1783, and Legendre, who had stated it in 1785, but failed in two published attempts to prove it. Gauss publishes his proof in *Disquisitiones arithmeticae*, written this year but not published until 1801. See also 1785 MATH.

Medicine & health

Physician Edward Jenner per-

forms the first immunization against smallpox by infecting a boy with cowpox (vaccinia virus). See also 1721 MED; 1797 MED.

Physics

Benjamin Thompson, Count Rumford, gives \$5000 each to the Royal Society and the American Academy of Arts & Sciences for provision of biennial medals to be awarded for outstanding research in heat or light. The Rumford Medal of the Royal Society, which is still awarded every two years to a scientist working in Europe, will be instituted in 1800. The American Academy of Arts & Sciences version of the medal will be first awarded in 1839. It will continue to be presented whenever the academy recognizes a suitable candidate.

Edward Jenner

[b. Berkeley, England, May 17, 1749, d. Berkeley, January 26, 1823]

In the late 1700s it was common knowledge in the English countryside that dairymaids who had become ill with cowpox did not catch the much deadlier smallpox. Jenner believed that people could be protected against smallpox by inoculating them with cowpox, a technique that came to be called vaccination. Jenner inoculated several people with material from dairymaids' cowpox lesions and detailed cases of people who had cowpox and later resisted smallpox. Publication of his findings in 1798 created much controversy, but vaccination against smallpox soon became widespread.



I Tools

Joseph-Michael Montgolfier invents the hydraulic ram, a system for lifting water to great heights using the kinetic energy of a small waterfall. The system is reintroduced in France during World War II.

1797

★ Astronomy

Treatise Concerning the Easiest and Most Convenient Method of Determining the Orbit of a Comet by Heinrich Wilhelm Matthäus Olbers [b. Arbergen, (Germany), October 11, 1758, d. Bremen, Germany, March 2, 1840] introduces new methods for calculating parabolic orbits. See also 1801 AST.

German-English astronomer Caroline Herschel [b. Hanover, (Germany), March 16, 1750, d. Hanover, January 9, 1848], who has been discovering new comets for the past 11 years, discovers her eighth. See also 1847 AST.

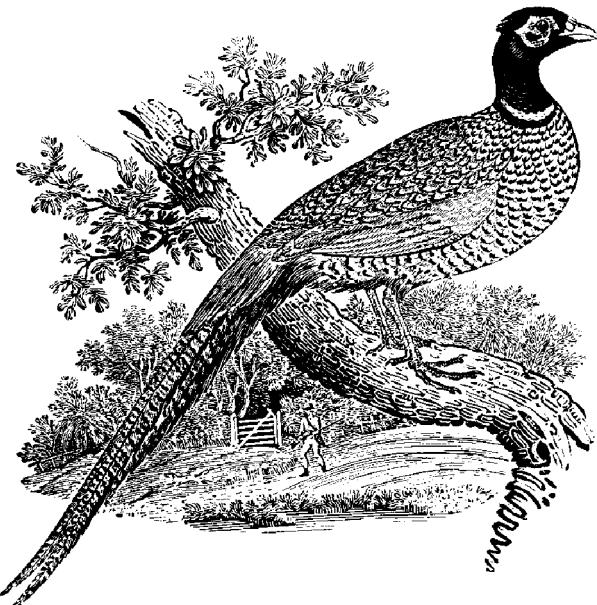
↗ Biology

History of British Birds by wood engraver Thomas Bewick [b. Northumberland, England, 1753, d. 1850] is published. See also 1827 BIO.

Marie-François-Xavier Bichat [b. Thoirette, France, November 14, 1771, d. Lyon, France, July 22, 1802] identifies 21 different types of tissue in animals, such as bone, muscle, blood, and so forth. See also 1801 MED.

⚗ Chemistry

William Nicholson begins publication of *Journal of Natural Philosophy, Chemistry and the Arts*. See also 1790 PHY; 1810 MATH.



PHEASANT FROM BEWICK'S *BRITISH BIRDS* Thomas Bewick discovered that using hardwood instead of softwood for engraving produces finer detail. He cut his drawings of birds directly into the wood from which they were printed.

Louis-Nicolas Vauquelin [b. St. André, Calvados, France, May 16, 1763, d. St. André, Hértot, France, November 14, 1829] discovers the element chromium (Cr).

A crowd of angry English people set Joseph Priestley's church and house in Birmingham on fire. The crowd is angry because Priestley had celebrated the second anniversary of the fall of the Bastille, thus supporting the French Revolution. Priestley and his family escape, although his laboratory and scientific papers are destroyed. Priestley later emigrates to the United States.

🌐 Earth science

In a series of experiments, chemist and geologist Sir James Hall [b. Haddington, Scotland, January 17, 1761, d. Edinburgh, Scotland, June 23,

1832] proves that igneous rock cools to form crystalline rock. See also 1777 EAR.

❖ Materials

About this time Josiah Spode II [b. 1755, d. 1827] in England adds bone ash to hard-paste porcelain, producing the first standard English bone china.

Σ Mathematics

Geometria del compasso ("geometry of compasses") by Lorenzo Mascheroni [b. Bergamo, Italy, May 13, 1750, d. Paris, July 14, 1800] contains Mascheroni's surprising result that all geometric constructions possible with a straight-edge and compass are also possible with compass alone (anticipated by 125 years by Denmark's Georg Mohr). See also 1672 MATH.

Joseph-Louis Lagrange's

Théorie des fonctions analytiques ("theory of analytic functions") attempts to avoid infinitesimals by use of infinite Taylor series derived from functions (hence the name "derivative"). The book introduces the notation $f'(x)$, $f''(x)$, etc. for the first, second, etc. derivatives. See also 1715 MATH.

♥ Medicine & health

The Royal Society rejects Edward Jenner's inoculation technique for smallpox. See also 1796 MED; 1800 MED.

I Tools

Edmund Cartwright patents a metal packing for piston rods. See also 1816 TOOL.

Engineer Henry Maudslay [b. Woolwich, England, August 22, 1771, d. Lambeth, England, February 14, 1831] perfects the slide rest for lathes, called one of the great inventions of history; it permits the lathe operator to operate the lathe without holding the metal-cutting tools in his hands. See also 1781 TOOL; 1800 TOOL.

↗ Transportation

Robert R. Livingston [b. New York, November 27, 1746, d. Clermont, New York, February 26, 1813] brings Samuel Morey to New Jersey to develop faster steamboats. The company fails, but Morey's concept of side paddle wheels is passed along by Livingston to Robert Fulton [b. Little Britain, Pennsylvania, November 14, 1765, d. New York, February 24, 1815], who uses it in the first commercially successful steamships. See also 1795 TRAN; 1826 TRAN.

John Fitch is possibly the first person to apply the screw pro-

peller to a steamboat. Although both Benjamin Franklin and Thomas Jefferson recall seeing a boat propelled with a screw on the Seine at Paris, it is not clear that steam was also used. *See also* 1787 TRAN; 1836 TRAN.

Some English roadways in Shropshire are converted to iron rails along which wagons are drawn by horses. *See also* 1785 TRAN; 1801 TRAN.

1798

▲ Archaeology

Napoleon Bonaparte, after conquering most of Egypt, establishes the Institut d'Egypte, staffed with French scholars who, among other studies of Egypt, begin the study of ancient temples and tombs. *See also* 1799 ARCH.

★ Astronomy

German astronomers Heinrich W. Brandes [b. 1777, d. 1834] and Johann F. Benzenberg [b. 1777, d. 1846] use triangulation to measure the height of meteors as they burn in the atmosphere.

Pierre-Simon Laplace uses Newton's concept of light as particles to predict the existence of what are essentially black holes — stars so big that

the escape velocity for particles exceeds the speed of light. *See also* 1784 AST; 1939 AST.

The first volume of James Bradley's catalog of stellar positions is published posthumously. *See also* 1762 AST.

◊ Chemistry

Louis-Nicolas Vauquelin discovers beryllium (Be) in the gems beryl and emerald, but does not isolate the element. Beryllium will finally be isolated by Friedrich Wöhler in 1828.

◆ Communication

Aloys Senefelder [b. Prague, (Czech Republic), November 6, 1771, d. Munich, 1834] invents lithography. Having made a note on a stone plate with a wax-based ink because paper is not at hand, he has the idea to treat the stone plate with acid, causing the surface protected by the ink to stand out in relief and making it possible to use it for block printing. *See also* 1808 COMM.

❖ Ecology & the environment

Essay on the Principle of Population As It Affects the Future Improvement of Society (published anonymously) by economist Thomas Robert Malt-

hus [b. near Guilford, Surrey, England, February 13, 1766, d. Haileybury, Somersetshire, England, December 23, 1834] projects an expanding population that can only be controlled by famine, disease, or war. *See also* 1803 ECOL.

❖ Energy

William Murdoch demonstrates the use of coal gas for lighting Boulton & Watt's plant in Soho. *See also* 1786 ENER; 1799 ENER.

◊ Materials

Nicolas Louis Robert [b. Paris, 1761, d. Dreux, France, 1828] invents a machine for the continuous production of paper. Previously, paper could only be manufactured in separate sheets. *See also* 1666 MATR; 1807 MATR.

Pierre-Simon Girard's *Traité analytique de la résistance des solides* ("analytic treatise on resistance in solids") reports on his own experiments with bending of beams and also provides a history of structural mechanics and an introduction to what is known about strength of materials at the time. *See also* 1744 MATR; 1807 MATR.

Σ Mathematics

Norwegian surveyor Caspar

Wessel [b. Vestby, Norway, June 8, 1745, d. Copenhagen, Denmark, March 25, 1818] publishes in the *Transactions of the Danish Academy* the method of representing complex numbers as points in a plane. This useful visualization is generally attributed to Gauss or to Jean-Robert Argand, who each will independently develop the same idea. *See also* 1806 MATH.

❖ Physics

Enquiry Concerning the Source of Heat Which Is Excited by Friction by American-British physicist Count Rumford (Benjamin Thompson) describes his experiments with boring cannons that show that the caloric theory of heat cannot be true and that heat should be considered a kind of motion. *See also* 1724 PHY.

Henry Cavendish determines the mass of Earth by measuring the force of gravity between two small masses and two large masses. This experiment determines the gravitational constant G , the only unknown value in Newton's equations. Solving for G enables Cavendish to establish that Earth is about 5.5 times as dense as water. *See also* 1774 EAR; 1854 EAR.



Count Rumford (Benjamin Thompson)

[b. Woburn, Massachusetts, March 26, 1753, d. Auteuil, near Paris, August 21, 1814]

Benjamin Thompson grew up in the American colonies and became a spy for the British, which forced him to flee to England in 1776. He worked for the British government and was knighted by King George III in 1784. He then moved to Munich in southern Germany, where he was made a count of the Holy Roman Empire: Count Rumford.

Rumford's major scientific contribution concerned the nature of heat. At that time it was widely believed that heat is a fluid form of matter. While boring (drilling out) cannons, Rumford discovered that more heat was released than could possibly have been contained in the metal. He concluded that the process of boring produced the heat, and said that heat should be considered a form of motion. Rumford applied his understanding of heat to improving fireplaces so that they better reflected heat and carried away smoke. He invented the kitchen stove, drip coffeepot, pressure cooker, and thermal underwear.

✈ Transportation

The 2-km (1-mi) Sault Ste. Marie Canal joining lakes Huron and Superior is completed by the Northwest Fur Company. The small lock with a depth of about 0.5 m (1.5 ft) is the first in North America. Even today some authorities reckon the Sault Ste. Marie as the busiest canal in the world. *See also* 1794 TRAN; 1829 TRAN.

Robert Fulton builds a four-person submarine, the *Nauutilus*. *See also* 1775 TRAN.

1799

▲ Archaeology

In August and September French scholars known as the *hiéroglyphistes* measure and map the ruins at Thebes in Egypt. Soldiers in Napoleon's army, digging near the Rosetta branch of the Nile, uncover a stone engraved in three different languages. The Rosetta Stone turns out to be the key to unlocking Egyptian hieroglyphics. *See also* 1798 ARCH; 1822 ARCH.

★ Astronomy

Naturalist Baron Friedrich Heinrich Alexander von Humboldt [b. Berlin, September 14, 1769, d. Berlin, May 6, 1859] starts his five-year exploration of the Spanish colonies of the New World. While exploring the Orinoco River in South America von Humboldt observes the Great Leonid meteor shower, later making one of the first known scientific accounts of the shower. *See also* 1833 AST.

Pierre-Simon Laplace's first of five volumes *Traité de mécanique céleste*, known generally as *Mécanique céleste*

("celestial mechanics"), begins his summary of the advances in mathematical astronomy made during the 18th century. The last volume will not be issued until 1825. *See also* 1787 AST; 1829 AST.

❖ Biology

In *The Naturalist's Miscellany* British zoologist George Shaw gives the first scientific account of the duck-billed platypus, based on a skin and a sketch provided by a former governor of New South Wales in Australia.

▷ Chemistry

Chemist Antoine-François, comte de Fourcroy [b. Paris, June 15, 1755, d. Paris, December 16, 1808], isolates urea. *See also* 1828 CHEM.

Joseph-Louis Proust [b. Angers, France, September 26, 1754, d. Angers, July 5, 1826] finds that the elements in a compound always combine in definite proportions by mass (Proust's law). *See also* 1811 CHEM.

⌚ Communication

The Royal Institution of Science is founded in England; its aim is furthering technology by means of science. *See also* 1660 COMM.

✉ Earth science

A perfectly preserved mammoth is found frozen in Siberia.

Alexander von Humboldt describes the rock of the Jura Mountains as *Jurassic*, a term that will be adopted in the 1830s as a part of the geologic time scale by Leopold von Buch. *See also* 1822 EAR.

❖ Energy

Phillipe Lebon [b. Brachay, France, May 29, 1767, d. Paris, December 2, 1804] receives a patent for his "Thermolampe," which uses gas distilled from wood for lighting. *See also* 1792 ENER; 1801 ENER.

Wilhelm Lampadius [b.

Hehlen, (Germany), August 8, 1772, d. Freiburg, Germany, April 13, 1842], experiments with coal gas for lighting in the palace of the Elector of Saxony at Dresden (Germany). *See also* 1798 ENER; 1801 ENER.

William Murdoch builds a rotary steam engine based on a pump design by Pappenheim in 1636. Sealing problems cause the engine to have a very low efficiency. The same year Murdoch patents the slide valve, which will replace the drop valves used in steam engines up to that time. *See also* 1802 ENER.

❖ Materials

Charles Tennant [b. Ochiltree, Scotland, 1768, d. 1838] invents bleaching powder, calcium hypochlorite. Bleaching is also introduced in the manufacture of paper, for which colored rags may now be used as well as white ones.

Σ Mathematics

Gaspard Monge's *Géometrie descriptive* ("descriptive geometry") consists of his 1794–95 lectures at the Ecole Normale in Paris and provides the first printed account of descriptive geometry (geometry in three dimensions as shown on a plane, the basis for mechanical drawing). *See also* 1763 MATH.

Gauss's doctoral dissertation, "New Proof of the Theorem

that Every Integral Rational Function of One Variable Can Be Decomposed into Real Factors of the First or Second Degree," is the first successful proof of the fundamental theorem of algebra, that every polynomial equation has a solution.

Teorie generale delle equazioni ("general theory of equations") by Paolo Ruffini [b. Valentano, (Italy), September 22, 1765, d. Modena, (Italy), May 10, 1822] contains the first proof that the general equation of the fifth degree cannot be solved by algebraic methods based on radicals, although the proof is flawed or unclear in some details. *See also* 1824 MATH.

✈ Transportation

George Cayley designs the first flying machine configured with fixed wings, control surfaces on the tail, and a means of propulsion. *See also* 1804 TRAN.

1800

★ Astronomy

The "Celestial Police," presided over by Johann Schröter [b. Erfurt, Germany, August 30, 1745, d. August 20, 1816], are founded at Lilenthal to search for a "missing planet" between Mars and Jupiter. Such a planet should be found according to the rule of thumb known as Bode's law. *See also* 1772 AST.

❖ Biology

Karl Friedrich Burdach [b. Leipzig (Germany) June 12, 1776, d. Königsberg (Kalinigrad, Russia), July 18, 1847] introduces the word *biology* to denote the study of human

Sir George Cayley

[b. Scarborough, Yorkshire, England, December 27, 1773, d. Brompton, England, December 15, 1857]

As a child Cayley became interested in the possibility of heavier-than-air flight. Throughout his life he created model helicopters and gliders that flew, working out the main principles of heavier-than-air flight for the first time. Although one of his gliders carried a human pilot aloft, the only available engines of his time were heavy steam devices, too massive for flight. Cayley is also credited with inventing the tractor that runs on treads instead of wheels and a number of other useful devices.

morphology, physiology, and psychology. In 1802 Gottfried Treviranus [b. Bremen, (Germany), February 4, 1776, d. Bremen, February 16, 1837] and Jean-Baptiste Lamarck independently expand biology's meaning to include the study of all living things.

Chemistry

William Nicholson and Sir Anthony Carlisle [b. Stillington, England, 1768, d. London, 1840], using the newly developed voltaic battery, perform the first electrolysis of water, reversing earlier experiments that showed that hydrogen and oxygen combine to form water. *See also* 1777 CHEM; 1805 CHEM.

Communication

Charles Lord Stanhope [b. London, August 3, 1753, d. Chevening, Kent, England, December 15, 1816] invents the iron printing press and starts using such presses in London.

Energy

British engineer Richard Trevithick [b. Illogan, England, April 13, 1771, d. Dartford, Kent, England, April 22, 1833] builds the first full-sized steam engine to use high-pressure steam. *See also* 1785 ENER; 1802 ENER.

Alessandro Volta announces his invention, made in 1796 or 1799, of the electric battery,

also known as the voltaic pile. It consists of a stack of alternating zinc and silver disks separated by felt soaked in brine and is the first source of a steady electric current. *See also* 1775 ENER; 1816 ENER.

Bertrand Guillame Carcel [b. 1750, d. Paris, 1812] adds a clockwork pump to the Argand lamp, producing a steadier light. *See also* 1784 ENER.

Food & agriculture

Copper sulfate, hydrogen cyanide, lead arsenide, nicotine, petroleum, and turpentine are used in fighting plant diseases. *See also* 1763 FOOD; 1825 FOOD.

The pasta machine for making macaroni is invented in Naples. Previously, pasta of all shapes had been made by hand.

Medicine & health

Humphry Davy investigates nitrous oxide ("laughing gas") on April 9 and suggests its use as an anesthetic. *See also* 1774 CHEM; 1844 MED.

Benjamin Waterhouse [b. Newport, Rhode Island, March 4, 1754, d. Cambridge, Massachusetts, October 2, 1846] is the first American physician to use smallpox vaccine (on his son). *See also* 1797 MED.

Chlorine is used to purify water by William Cruikshank [b. Edinburgh, Scotland, 1745, d. June 27, 1800] in England.

In *Leçons d'anatomie comparée* ("lessons in comparative anatomy"), which is published from this year until 1805, Georges Cuvier lays the foundations of comparative anatomy.

Physics

William Herschel's "An Investigation of the Powers of Prismatic Colours to Heat and Illuminate Objects" tells of his discovery of infrared radiation. While investigating the power of different parts of the solar spectrum produced by a prism to heat a thermometer, he finds that invisible light

beyond the red produces the most heat. *See also* 1801 PHY.

I Tools

Henry Maudslay builds the first lathe that enables the operator to make screws of any desired pitch or diameter. *See also* 1797 TOOL.

1801**Archaeology**

Thomas Bruce, Lord Elgin [b. 1766, d. 1841], with permission of the Turkish government that controls Athens, begins the removal of sculptured portions of the Parthenon, a task that takes five years to complete. He ships these to England, where they become known as the Elgin Marbles. *See also* 432 BCE CONS; 1816 ARCH.

Astronomy

Giuseppe Piazzi [b. Ponte de Valtellina, Switzerland, July 16, 1746, d. Naples, (Italy), July 22, 1826] discovers the first asteroid, Ceres, at Palermo (Italy), January 1. From data obtained in a brief 41 days of observation, Gauss calculates the orbit of the new planet, a feat he will repeat for the next three asteroids to be discovered, Pallas, Juno, and Vesta. *See also* 1800 AST; 2001 AST.

**Sir Humphry Davy**

[b. Penzance, England, December 17, 1778, d. Geneva, Switzerland, May 29, 1829]

In 1807 Davy constructed the most powerful electric battery to that time and began to perform electrolysis on available materials. Metallic potassium emerged easily from molten potash and metallic sodium from lye. The next year Davy used improved methods to obtain the first samples of barium, calcium, magnesium, and strontium. He also independently produced boron a few days after its first discoverers and was the first to recognize chlorine as an element. His invention of the miner's safety lamp in 1815 saved many lives and his electric arc lamp of 1809 was the start of electric lighting.

Bibliographie astronomique (“astronomical bibliography”) by Joseph-Jérôme Le Français de Lalande [b. Bourg-en-Bresse, France, July 11, 1732, d. Paris, April 4, 1807] lists the position of 47,000 stars. Also, Johann Elert Bode’s *Uranographia* is an atlas of 17,240 stars and nebulae. *See also* 1762 AST; 1911 AST.

生物学

Jean-Baptiste Lamarck’s *Système des animaux sans vertèbres* (“system for invertebrates”) includes a classification system for invertebrates and a preliminary view of his idea of evolution. *See also* 1794 BIO; 1815 BIO.

化学

John Dalton formulates his law of partial pressures for gases, which states that each component of a mixture of gases in a given container produces the same pressure as if it occupied the container by itself. *See also* 1787 PHY; 1803 CHEM.

Spanish-Mexican mineralogist Andrés Manuel Del Rio [b. Madrid, Spain, November 10, 1764, d. Mexico City, March 23, 1849] discovers the element vanadium (V), although he fails to convince other chemists at the time.

Charles Hatchett [b. London, January 2, 1765, d. Chelsea, England, March 10, 1847] discovers niobium (Nb), which he names columbium. Later, William Hyde Wollaston [b. Norfolk, England, August 6, 1766, d. London, December 22, 1828] disputes the identity of the metal, claiming that Hatchett had really identified tantalum. Hatchett will be vindicated, but his name will

be lost and the metal named for Niobe, a daughter of Tantalus. *See also* 1802 CHEM.

建筑

James Finley [b. Antrim, Ireland, 1756, d. Uniontown, Pennsylvania, 1828] builds a suspension bridge across Jacob’s Creek in western Pennsylvania with a span of 21 m (70 ft) using chains. Although Native Americans had constructed suspension bridges in the Andes hundreds of years earlier, the Finley bridge is the first modern suspension bridge. *See also* 1290 TRAN; 1809 CONS.

能源

Phillipe Lebon uses his wood-gas system to light the Hotel Seignelay in Paris, the first known instance of a whole building lighted with inflammable gas. *See also* 1799 ENER.

William Murdoch installs coal gas for lighting at the engine house of Boulton & Watt’s plant near Birmingham, England, to celebrate the short Peace of Amiens between Britain and France. *See also* 1792 ENER; 1803 ENER.

John Rennie uses steam engines for the construction of the London docks. *See also* 1789 ENER; 1810 FOOD.

数学

Gauss proves that every natural number is the sum of at most three triangular numbers, a conjecture first made by Fermat in 1636. *See also* 1636 MATH.

Gauss’s *Disquisitiones arithmeticae* (“arithmetical researches”) greatly extends number theory and introduces his concept of congruences, numbers that have the

same remainder when divided by a particular number. For example, 17 and 23 are congruent modulo (with respect to) 3 since the remainder of 17 divided by 3 is 2 and also the remainder of 23 divided by 3 is 2. *See also* 1760 MATH.

医药与健康

Thomas Young discovers the cause of astigmatism. *See also* 1864 MED.

Marie-François-Xavier Bichat publishes *Anatomie générale appliquée à la physiologie et à la médecine* (“general anatomy applied to physiology and medicine”), which investigates and names the tissues of the body and stresses the study of the different tissues making up organs. *See also* 1797 BIO; 1816 MED.

物理

Thomas Young discovers interference phenomena of light: light passing through two narrow slits produces an interference pattern, proving light is a wave phenomenon. The wave nature of light had previously been proposed in the 17th century by Robert Hooke, Francesco Grimaldi, and Christiaan Huygens, but Newton’s corpuscular theory of 1704 came to supersede it. *See also* 1678 PHY.

German astronomer Johann Georg von Soldner [b. July 16, 1776, d. May 18, 1833] predicts the effect of gravitation on light. *See also* 1919 AST.

Johann Wilhelm Ritter [b. Samitz, (Germany), December 16, 1776, d. Munich, Bavaria (Germany), January 23, 1810], working with silver chloride, finds that radiation beyond the spectrum of visible light — ultraviolet radiation —

exists. *See also* 1800 PHY; 1888 PHY.

工具

Joseph-Marie Jacquard [b. Lyon, France, July 7, 1752, d. Oullins, France, August 7, 1834] develops an early version of his loom in which each decision still must be carried out by a human operator. *See also* 1775 TOOL; 1805 TOOL.

Robert Hare [b. Philadelphia, Pennsylvania, January 17, 1781, d. Philadelphia, May 15, 1858] invents the hydrogen-oxygen blowpipe, the ancestor of modern-day welding torches. *See also* 1901 TOOL.

交通运输

The first freight cars are used on the Surrey Iron Railway in England. *See also* 1797 TRAN.

Richard Trevithick builds a full-scale steam-powered carriage, completed on December 24. It runs well for four days, but burns up when Trevithick carelessly allows all the water in the boiler to evaporate. *See also* 1789 TRAN; 1804 TRAN.

1802

考古学

On a bet with some drinking companions, Georg Friedrich Grotefend [b. Hanover, Germany, June 9, 1775, d. Hanover, December 15, 1853] becomes the first to translate a cuneiform text, a Persian inscription from Persepolis. Credit for such translations is usually given to Henry Creswicke Rawlinson [b. Oxfordshire, England, November 4, 1810, d. March 5, 1895], whose translation of old Persian cuneiform will be published in 1846. *See also* 1846 ARCH.

Alexander von Humboldt, on a five-year study of the natural history and geography of South America, visits Mexico and persuades church authorities to unearth the Aztec calendar stone and statue of Coatlicue. *See also* 1792 ARCH.

★ Astronomy

William Herschel publishes his third list of nebulae. In this year he also establishes the existence of binary star systems by showing that for some double stars, one star orbits the other. Previously, most astronomers believed that the stars are unrelated but appear near each other in the same line of sight. *See also* 1783 AST.

Wilhelm Olbers discovers Pallas, the second asteroid. *See also* 1801 AST; 1804 AST.

William Wollaston observes dark lines in the solar spectrum, which he suggests may be gaps between colors; but he fails to follow through on their significance. Joseph von Fraunhofer [b. Straubling (Germany), March 6, 1787, d. Munich, June 7, 1826], who observes them in 1814, is the first to suspect that they are important, but it is not until the work of Gustav Kirchhoff that they will be recognized as revealing the presence of specific elements in the Sun. *See also* 1859 AST.

Chemistry

Joseph Louis Gay-Lussac [b. Haute Vienne, France, December 6, 1778, d. Paris, May 9, 1850] shows that all gases at a given pressure increase by the same percentage in volume when subjected to the same increase in temperature. *See also* 1787 CHEM.

Anders Gustaf Ekeberg [b. Stockholm, Sweden, January 15, 1767, d. Uppsala, Sweden, February 11, 1813] discovers the element tantalum (Ta).

Communication

The U.S. Military Academy at West Point, New York, is established as the headquarters of the engineering corps of the U.S. army. The first engineering school in the New World, it remains entirely a school for training engineers until 1866. *See also* 1751 COMM.

Thomas Wedgwood [b. Staffordshire, England, May 14, 1771, d. Dorsetshire, England, July 10, 1805] announces to the British Royal Institution that he has found a method for creating images on nitrate of silver using a camera obscura. *See also* 1727 COMM; 1810 COMM.

Earth science

The first edition of *System of Chemistry* by Thomas Thomson [b. Crieff, Scotland, April 12, 1773, d. July 2, 1852] expands on a symbolic representation of minerals classed by genus that he first introduced in an article written about 1798. He uses such symbols as A for alumina, M for magnesia, C for chrome, and so forth. The system is often considered an important precursor to the modern system of chemical symbols. *See also* 1811 CHEM.

Illustrations of the Huttonian Theory by John Playfair [b. Benvie, Scotland, March 10, 1748, d. Edinburgh, Scotland, July 20, 1819] explains James Hutton's theory that erosion and sedimentation have shaped the surface of Earth. *See also* 1785 EAR; 1833 EAR.

Energy

Humphry Davy demonstrates that metal strips can be heated to incandescence by passing a sufficiently strong electric current through them. He also observes the electric arc, but does not use it for lighting. *See also* 1809 ENER.

Richard Trevithick obtains a patent for both his high-pressure steam engine and his steam carriage. The title of the patent is "Steam engines — Improvements in the construction thereof and Application thereof for driving Carriages." *See also* 1800 ENER.

Matthew Murray [b. Newcastle, England, 1765, d. 1826] builds a rotary-motion steam engine mounted on a "bedplate," a cast-iron foundation on which all the parts of the engine are mounted. The bedplate does away with the requirement of supporting the engine components by masonry or building structures and becomes generally adopted a few years later. *See also* 1799 ENER.

William Symington [b. Leadhills, England, 1763, d. London, March 1831] builds a direct-action steam engine for the paddle tug *Charlotte Dundas*. In such an engine the piston rod is directly connected via a connecting rod to the crankshaft.

Food & agriculture

Chemist Franz Archard, an apprentice to Andreas Marggraf, founds the first factory for manufacturing sugar from beets. *See also* 1747 FOOD; 1822 FOOD.

Alexander von Humboldt returns from South America with samples of guano, the droppings of pelicans and

other birds long used by the natives of Peru as fertilizer. Mined from islands off the coast of Peru, guano becomes a widely used fertilizer in Europe and North America until the development of artificial fertilizers. *See also* 1699 FOOD; 1820 FOOD.

Physics

Thomas Young's *On the Theory of Light and Colors* is the first of three pivotal papers describing his wave theory of light. *See also* 1801 PHY.

I Tools

Samuel Bentham [b. 1757, d. 1831] conceives of mass producing pulley blocks for the British navy. He enlists the help of engineer Marc Isambard Brunel [b. Hacqueville, France, April 25, 1769, knighted 1841, d. London, December 12, 1849], who aids in planning, and Henry Maudslay, who develops 44 separate machines for performing the operations. *See also* 1803 TOOL.

→ Transportation

Edward Massey invents and patents a ship's "log" that uses a rotor and gears to power a dial showing the distance a ship has traveled, although it must be hauled on board to be read. The ship's log will come into general use during the first half of the 19th century. *See also* 1846 TRAN.

The West India Docks, artificial basins in the Thames at London, designed and built in less than two years by William Jessop, open in August. *See also* 1826 TRAN.

Nathaniel Bowditch [b. Salem, Massachusetts, March 26, 1773, d. Boston, March 16,

1838] writes *New American Practical Navigator* and sets the standards for navigation of sailing ships. *See also* 1763 TRAN; 1843 TRAN.

The steamboat *Charlotte Dundas*, built by William Symington, operates as a towboat on the Firth and Clyde Canal, but does not prove profitable. *See also* 1797 TRAN; 1803 TRAN.

John C. Stevens [b. 1749, d. 1838] of Hoboken, New Jersey, builds a propeller-driven steamboat. *See also* 1797 TRAN; 1803 TRAN.

1803

★ Astronomy

Physicist Jean Baptiste Biot makes a study of meteorites found at L'Aigle, France, and determines that they do not originate on Earth. *See also* 1807 AST.

Biology

John C. Otto does the first banding studies on wild American birds.

Chemistry

English chemist John Dalton first puts forward his atomic theory of matter, stating that since chemicals combine only in integral proportions, atoms



Jean Baptiste Biot

b. Paris, April 21, 1774, d. Paris, February 3, 1862]

Biot was a physicist whose main discoveries affected astronomy, earth science, and chemistry. His 1803 report on a meteorite fall convinced scientists for the first time that rocks fall from the sky. His balloon flights with Joseph Louis Gay-Lussac established that Earth's magnetic field extends into the atmosphere. In 1815 Biot showed that some organic compounds have two chemically identical forms that rotate polarized light in different directions, correctly speculating that the effect is caused by differences in the shape of the molecules.

must exist. *See also* 1799 CHEM; 1807 CHEM.

William Henry [b. Manchester, England, December 12, 1775, d. 1836] formulates the law named after him that states that the mass of gas dissolved in a liquid is directly proportional to the pressure. *See also* 1801 CHEM.

Smithson Tennant [b. Selby, England, November 30, 1761, d. Boulogne, France, February 22, 1815] discovers the elements iridium (Ir) and osmium (Os).

Claude Louis Berthollet's *Essai de statique chimique* ("essay on static chemistry") shows that reaction rates not only depend on affinities — that is, the degree to which one element will combine with another — but also the amounts of reacting substances. His book reflects the first systematic attempt to deal with the physics of chemistry. *See also* 1789 CHEM; 1804 CHEM.

English chemist William Wollaston discovers the elements palladium (Pd) and rhodium (Rh). Palladium is named after the asteroid Pallas, discovered the previous year, rhodium after the color rose, observed in its salts.

Mineralogist Wilhelm Hisinger [b. Skinnskatteberg, Västmanland, Sweden, December 23, 1766, d. Skinnskatteberg, June 28, 1852] and Jöns Jakob Berzelius independently discover cerium (Ce).

Ecology & the environment

Thomas Malthus, in his second edition of *Essay on the Principles of Population*, suggests that "moral restraint" might prevent famine from overpopulation. *See also* 1798 ECOL.

Energy

William Murdoch lights his main factory with coal gas. It is the first building to be routinely lighted in this way. Murdoch had been the first to realize (in 1792) that coal gas might be used for light. *See also* 1799 ENER; 1806 ENER.

Richard Trevithick, while improving the safety of high-pressure boilers by installing double safety valves, introduces a rivet made from the metal lead mounted at the top of the boiler furnace. If the boiler boils dry, the rivet melts and allows steam to escape to the furnace. *See also* 1788 TOOL.

Records show that only six steam engines are in use in the United States.

Food & agriculture

A self-sharpening cast-iron plow is introduced in England. *See also* 1783 FOOD; 1819 FOOD.

Jöns Jakob Berzelius

[b. Sörgård, Sweden, August 20, 1779, d. Stockholm, Sweden, August 7, 1848]

Berzelius was the dominant chemist of the first part of the 19th century. He introduced the system of symbols we now use, divided chemistry into organic and inorganic branches, and introduced much of the basic vocabulary of chemistry — including such words as allotrope, catalysis, halogen, isomer, polymer, and protein. He was a careful experimenter and in 1828 created the first really good table of atomic masses, covering 28 elements, an important step toward the development of the periodic table. Berzelius's early endorsement of Dalton's atomic theory led to its general acceptance. As the author of a widely used textbook and the editor of a yearly review of chemical progress, however, he upheld many conservative ideas that we now know to be incorrect.



Σ Mathematics

Géométrie de position (“geometry of position”) by Lazare Carnot contains generalizations of well-known theorems of geometry as well as the development of various coordinate systems, including intrinsic coordinates — systems that are not bound to any particular choice of axes. See also 1637 MATH; 1827 MATH.

♥ Medicine & health

Johann Christian Reil [b. (Germany), 1759, d. 1813] proposes using psychology for treating mental disorders. See also 1777 MED.

I Tools

Engineer Marc Isambard Brunel develops and installs between this date and 1810 the first complete set of machine tools at the Portsmouth, England, dockyards for the mechanical production of ships' blocks, replacing manual operations completely. The tools are built by Henry Maudslay. As a result of mass production, 10 workers produce as many pulley blocks in a year as previously had been made by 110 workers. See also 1802 TOOL; 1810 TOOL.

→ Transportation

Robert Fulton's steamboat makes a successful trip on the Seine in France. See also 1802 TRAN. 1807 TRAN.

1804

★ Astronomy

Friedrich Wilhelm Bessel calculates the orbit of Halley's comet from 200-year-old observations by Thomas Harriot. See also 1758 AST.

German astronomer Karl Lud-

Friedrich Wilhelm Bessel

[b. Minden, Prussia (Germany), July 22, 1784, d. Königsberg, Prussia (Kalinigrad, Russia), May 17, 1845]

Mathematicians and physicists often use Bessel functions, developed by Bessel to analyze the motions of planets and stars. In 1838 Bessel was the first to measure the distance to a star (61 Cygni) using parallax and a special instrument he invented known as the heliometer. With the heliometer Bessel also discovered that Sirius has an unseen companion that causes its position to shift slightly as the companion orbits the larger star.



wig Harding [b. September 29, 1765, d. August 31, 1834] discovers the third asteroid, Juno. Wilhelm Olbers discovers the fourth known asteroid, Vesta. See also 1802 AST.

↗ Biology

Recherches chimiques sur la végétation (“chemical researches on vegetation”) by Nicholas de Saussure [b. Geneva, Switzerland, October 14, 1767, d. Geneva, April 18, 1845] shows that plants require carbon dioxide from the air and nitrogen from the soil. Earlier researchers had assumed that plants got carbon from the soil instead of from carbon dioxide in the air. See also 1648 BIO; 1817 BIO.

▷ Chemistry

Hans Christian Oersted proposes a theory of chemical forces based on combustion and compares those forces to electrical phenomena. See also 1803 CHEM.

⊕ Earth science

Jean Baptiste Biot and Joseph Louis Gay-Lussac ascend in a balloon to study terrestrial magnetism and Earth's atmosphere. See also 1912 AST.

▼ Energy

Arthur Woolf [b. Cornwall, England, November 4, 1766, d. Guernsey, England, October 26, 1837] patents a compound steam engine. He miscalculates the dimensions needed for the high-pressure and low-pressure cylinders, however, making the machine not very efficient. See also 1811 ENER.

Oliver Evans builds and demonstrates in Philadelphia a double-acting vertical high-pressure steam engine that uses a steam pressure of three atmospheres. See also 1802 ENER.

Frederick Albert Winsor (b. Friedrich Albrecht Winzer) [b. Brunswick, England, 1763, d. Paris, May 11, 1830] patents

an oven for the manufacture of coal gas. See also 1803 ENER.

■ Food & agriculture

Nicolas Appert invents canning foods as a means of preservation and opens the world's first canning factory. Along the way, he also invents the bouillon cube. See also 1795 FOOD; 1809 FOOD.

The soybean, which will become a major crop in the U.S. Midwest after World War II, is first cultivated in the United States. The bean had been known for over 3000 years in Asia. See also 1500 BCE FOOD.

Albert D. Thaer [b. Zelle, Germany, May 14, 1752, d. Moeglin, Germany, October 26, 1828] publishes *Grundsätze der rationellen Landwirtschaft* (“foundations of rational agriculture”), which explains the benefits of rotation of crops. See also 1645 FOOD; 1838 FOOD.



Hans Christian Oersted

[b. Rudkøbing, Denmark, August 14, 1777, d. Copenhagen, March 9, 1851]

Oersted recognized that electricity and magnetism are probably related. In 1820 he demonstrated this by placing a magnetic compass below an electric current. The current caused the needle to move perpendicular to the wire. Oersted performed other first-class experimental work in both chemistry and physics.

Machine tools

Machine tools are devices used to build parts of machines; but usually the concept is interpreted more narrowly, denoting tools that cut or drill, press or shear, or otherwise shape hardened materials into specific forms. Although casting is often one of the most important steps in producing a part, casting per se does not use machine tools. A mold may, however, have been shaped by machine tools. A classic description of how a sculptor works says that the sculptor takes a block of marble and removes everything that does not look like the statue in mind. Most machine tools work the same way, removing metal or ceramic a little at a time until the part the designer had in mind is all that is left.

The first machine tool was among the first machines invented; the bow drill goes back at least to Neolithic times. But the main ancestor of machine tools was not a machine tool itself. The potter's wheel, dating from about 6000 years ago, was originally used to shape soft material only. It cannot count as a machine tool because clay is not hard until after firing. By classical Greek times, however, the potter's wheel had become a part-time machine tool, helping smooth imperfections from fired pottery.

Although records are scarce, that application of the potter's wheel apparently merged imperceptibly into the principal machine tool used even today, the lathe. A lathe is a device for rotating a hard object, originally wood and later mostly metal, so that the object can be shaped by a stationary cutter. We know that early lathes had been developed because we find parts such as chair legs that had clearly been produced by "turning" on a lathe. But it is not until the 15th century, when Leonardo drew a lathe, that we learn anything about the device apart from its products. Leonardo's lathe is thought not to have been an invention, but a then-common type of wood lathe with a treadle and a spring pole.

During the 16th century, the art of lathe making advanced, and the lathe was adapted for making screws. Although early screws were used as fasteners, the application of screws for delicate adjustments was far more important. This use of screw adjustors ensured the accuracy of the machine parts produced. In addition to screw making, various adaptations of lathes throughout the 17th century using cams and patterns enabled the wood lathe to cut complicated figures, not just circles with different radii.

The 18th century began with a metal-cutting lathe built in 1701, but its builder clearly stated that his was not the first such lathe, but one of a very few. By the end of the century, however, metal lathes were much more common. Jacques de Vaucanson was among the first builders of the heavy, industrial lathe, which appeared in France before it did in England. A surviving lathe by

Vaucanson was apparently built between 1770 and 1780. The English soon surpassed the French, however. English lathes by Henry Maudslay, built in the early 19th century, set the standard for the time. Maudslay turned out in his shop not only the best lathes of the time, but also the best machine tool manufacturers. Almost all the machine builders of the Industrial Revolution in Britain can trace their heritage directly or indirectly to Maudslay's shop.

Maudslay's reputation and the place of machine tools in industry were both set during a seminal operation at the Portsmouth Naval Yard at the start of the 19th century. Using a system set up by Marc Brunel and Samuel Bentham, the production of pulleys (known to shipbuilders as "blocks") was completely mechanized. Although this operation had been partly mechanized as early as 1780, the new system used a special tool for each step in the operation. The arrangement was copied so extensively in the United States and blended so well with earlier U.S. developments of standardized parts in gun manufacture, that the whole process came to be called the "American system" of manufacture.

The lathe is the basic machine tool. Variations on the lathe, such as boring machines, grinders, milling machines, and planers, all of which use rotary motion to remove unwanted material, leaving the partly or completely finished part, are generally considered separately. These tools, all of which advanced in the mid-19th century, were also essential to the growth of industry. The cannon-boring machine, adapted to making strong cylinders for steam engines, is often cited as a key development.

Standardized parts and mass production are worthless without excellent measurement standards, as early standardizers found, often to their dismay. Concurrent with and necessary to the development of good machine tools was the development of better ways to measure parts. Joseph Whitworth, from Maudslay's shop, was one of the first to recognize this, developing various standards, including the bench micrometer, that improve accuracy from "can't fit a well-worn penny between the parts" early in the 19th century to one ten-thousandth of an inch or better by the middle. Whitworth also introduced plug-and-ring gauges, which led to the first "go-no-go" gauges — if the part was right it would fit into the larger or "go" gauge but not quite fit in the "no-go" smaller gauge. By the end of the 19th century gauge blocks that could be combined to measure with accuracies of a millionth of an inch were available. These tools were used to measure other tools that were sometimes in turn used to measure other ones; although there was some loss in precision along the way, the tools used in the shop could always be recalibrated as necessary by the experts. As a result, standardized parts produced by machine tools could become fully interchangeable all over the world.

* Physics

An Experimental Inquiry into the Nature and Propagation of Heat by Sir John Leslie [b. Largo, Scotland, April 16, 1766, d. Coates, Scotland, November 3, 1832] establishes that the transmission of heat by means of radiation has the same properties as the propagation of light. We now recognize that radiant heat is infrared light and other forms of electromagnetic waves. *See also* 1801 PHY; 1888 PHY.

→ Transportation

Richard Trevithick develops a steam locomotive that runs on iron rails and successfully hauls ten tons of iron 14.5 km (9 mi) on February 21. *See also* 1801 TRAN; 1808 TRAN.

On December 1 pioneer of aerial navigation George Cayley develops his first instrument to measure air resistance. During this year he also begins to build a series of gliders that will determine the basic principles of aerodynamics. He writes, but does not publish, his *Essay on the Mechanic Principles of Aerial Navigation*. *See also* 1799 TRAN; 1808 TRAN.

1805

↗ Biology

Pierre André Latreille [b. Brives, France, November 29, 1762, d. Paris, February 6, 1833] publishes the last volumes of his 14-volume *Histoire naturelle générale et particulière des crustacés et des insectes* (“comprehensive natural history of crustaceans and insects”), which began publication in 1802. *See also* 1775 BIO.

◊ Chemistry

German chemist Friedrich Wilhelm Sertürner [b. Neuhaus, (Germany), June 19, 1783, d. Hameln, Germany, February 20, 1841] isolates morphine from opium. *See also* 1832 MED.

Joseph Louis Gay-Lussac proves that water consists of two parts hydrogen and one part oxygen by volume, and that other gases also combine to form compounds in ratios that are integral. *See also* 1800 CHEM; 1808 CHEM.

■ Construction

Theodore Burr, starting in 1803, completes a combination truss-and-arch bridge over the Hudson River at Waterford, New York. *See also* 1792 CONS; 1820 CONS.

Thomas Telford completes the Pontcysyllte Aqueduct over the Dee River, which opens on November 26. More than 36 m (120 ft) high, the aqueduct carries the Shropshire Union Canal across the river in a 307 m (1007 ft) iron trough. *See also* 1845 CONS.

↗ Energy

Matthew Murray designs a “portable” steam engine that becomes the prototype of marine engines of the next 40 years. *See also* 1802 ENER.

◊ Materials

The British win the battle of Trafalgar in part because inferior French cast-iron cannons tend to burst when they are fired. *See also* 1415 MATR.

♥ Medicine & health

Über die Verrichtungen des Gehirns (“on the activities of the brain”) by Franz Joseph

Gall [b. Tiefenbrunn (Germany), March 9, 1758, d. Paris, 1828], while correct in showing that different parts of the brain have different functions, incorrectly states that the brain can be studied by examining the shape of a person’s skull — phrenology, as it came to be known. *See also* 1810 MED.

* Physics

Pierre-Simon Laplace measures molecular forces in liquids and announces his theory of capillary action.

I Tools

Joseph-Marie Jacquard develops a method of controlling the operation of a loom based on punched cards, an idea that will be used in early computers. *See also* 1801 TOOL; 1890 COMP.

→ Transportation

The largest canal tunnel in England, the Blisworth Tunnel on the Grand Union Canal, is completed; it is 930 m (3056 ft) long, 4.6 m (15 ft) wide, and 3.25 m (10.75 ft) high. *See also* 1789 TRAN.

1806

◊ Chemistry

Nicholas Clément [b. 1779, d. 1841] and Charles Désormes [b. Dijon, France, 1777, d. 1862] show how saltpeter acts as a catalyst in producing sulfuric acid by facilitating the transfer of oxygen from the air to burning sulfur. *See also* 1816 CHEM.

Louis-Nicolas Vauquelin and Pierre Jean Robiquet [b. 1780, d. 1840] isolate asparagine, the first amino acid to be discovered. Vauquelin and

Valentin Rose isolate quinic acid. *See also* 1900 BIO.

↳ Communication

Joseph Bramah invents a printing machine for bank notes that automatically numbers them.

↗ Energy

Frederick Winsor forms the world’s first coal-gas lighting company, originally called the National Light and Heat Company but later known as the Gas Light and Coke Company. *See also* 1807 ENER.

William Murdoch lights the very large Philips and Lee factory at Salford, England, with coal gas. About the same time, Samuel Clegg [b. Manchester, England, March 2, 1781, d. Middlesex, England, January 8, 1861] uses coal gas to light a mill in Halifax, England. *See also* 1803 ENER; 1812 ENER.

II Food & agriculture

In Germany the first gymnasium (similar to a U.S. high school) devoted to preparing students for agriculture opens.

Σ Mathematics

Adrien-Marie Legendre’s *Nouvelles méthodes pour la détermination des orbites des comètes* (“new method for finding comet orbits”) contains the first printed description of the method of least squares, a technique for finding the best approximation to observed data from isolated data points, discovered independently about ten years earlier by Gauss. Gauss will not publish his proof until 1809. *See also* 1801 AST; 1809 MATH.

Railroads, trains, and locomotives

The language used in discussing the method of using a powerful, self-propelled vehicle to pull one or more passive wheeled vehicles along a special roadway in which flanged wheels travel on a pair of equidistant supports tells a lot about the history of this important mode of transportation. There is no really satisfactory overall word to describe this means as a whole, as say *automobile* is sufficient for a personal transport system based on self-propelled vehicles. Instead, we say *railroad* or *railway* (really just the supports), *locomotive* (the self-propelled puller), or *train* (the line of vehicles being pulled). This correctly suggests that the components of what we shall call a railroad (using the support system for the whole) arose separately.

The support system gets the credit because it really was the first to arrive on the scene. Planked roads in and out of mines go back very far in history and had evolved into rails as early as 1556; we know this from an illustration in Agricola's book on mining. Two hundred years later, when iron began to be plentiful, wooden rails started to be covered with iron flanges to reduce wear.

Although one can assume that initially single vehicles were used on the first railways, miners learned that it was more efficient to use several vehicles linked together, pulled by mules, oxen, donkeys, or horses in different mines. Thus the railway came to be associated with the train of vehicles used on it. In the early 19th century, such railways had gone beyond the mines and

were being used to haul goods to canals. In England more than 20 such rail lines, with trains pulled by animals, had been authorized early in the 19th century.

Steam engines large enough to pull themselves — locomotives — or themselves and a train were too heavy for dirt or even gravel or paved roads, although some that were tried on roads were no heavier than modern sports utility vehicles. Furthermore, the earliest steam engines were associated with mines, where people were used to railways. So the combination that we know as the railroad system was fixed early in the 19th century: a locomotive on rails pulling a train.

Such locomotives were the first vehicles in which turning wheels supplied the power to move forward. In all previous vehicles, humans or other animals moved forward by walking or running, and the wheels were used mainly to reduce friction with the roadway.

At the beginning of the 19th century, people did not believe that a machine could be built that was strong enough to move itself and any significant load as well. Railroad pioneer Richard Trevithick won a significant bet of 500 guineas by pulling ten tons of iron and more than 70 passengers a distance of 14.5 km (9 mi) in southern Wales. When the engine arrived at the mine, it was left there to power stationary machinery.

Even after Trevithick's demonstration, it was generally believed in England that a locomotive could only pull loads on level rails. No early English railroad lines ran up hills — instead, they went around them or cut through them (which, along with cuts for canals, greatly improved the study of geology).

Essay on a Method of Representing Imaginary Quantities in Geometric Constructions by Jean-Robert Argand [b. Geneva, Switzerland, July 18, 1768, d. Paris, May 13, 1822] uses complex numbers to show that all algebraic equations have roots, but the proof is not rigorous. He also introduces the Argand diagram representation of complex numbers. *See also* 1798 MATH.

I Tools

Johann Beckmann publishes *Entwurf einer Allgemeinen Technologie* ("sketch of German technology"), in which he describes technology as a science.

About 30,000 Congreve rock-

ets, developed by Sir William Congreve [b. Woolwich, England, May 20, 1772, d. Toulouse, France, May 16, 1828], are used in the bombardment of Copenhagen.

1807

★ Astronomy

Nathaniel Bowditch determines that the Connecticut meteorite of 1807 once weighed 6,000,000 tons. *See also* 1803 AST.

□ Chemistry

Humphry Davy discovers the element potassium (K) by electrolysis of potash on October 6 and the element sodium

(Na) on October 13, by electrolysis of soda.

Jöns Jakob Berzelius classifies chemicals as either organic or inorganic. *See also* 1808 CHEM.

Thomas Thomson's *System of Chemistry* (third edition) contains Dalton's theory of atoms, explained for the first time. *See also* 1802 EAR.

Clergyman Alexander John Forsyth [b. Scotland, December 28, 1769, d. June 11, 1843] invents percussion powder, which leads to a way to ignite the charge in a cannon without using a match or burning stick. *See also* 1833 MATR.

Chemistry Applied to the Arts by Jean Antoine Claude Chap-

tal, Comte de Chanteloup [b. Nogaret, France, June 4, 1756, d. Paris, July 30, 1832] is the first book on industrial chemistry.

↳ Communication

William Wollaston invents the camera lucida about this time. This is a device that produces images of drawings on another sheet of paper, allowing them to be copied (by tracing over the image) or enlarged or reduced. *See also* 1553 COMM.

⊕ Earth science

The Geological Society of London becomes the first scientific society devoted to the newly named science of geology. *See also* 1779 EAR; 1811 EAR.

► Energy

George Cayley invents the calorific, or hot-air, engine, which will be used extensively in 19th-century industry. *See also* 1833 ENER.

Frederick Winsor's National Light and Heat Company installs coal gas lights on Pall Mall in London, although this is not immediately followed by any further success. *See also* 1812 ENER.

❖ Materials

Thomas Young introduces the concept now known as Young's modulus, found as stress divided by strain, which measures elasticity or flexibility of a material. *See also* 1798 MATR; 1826 MATR.

In England the Fourdrinier brothers, Henry [b. 1766, d. 1854] and Sealy [d. 1847], make a commercial version of the Nicolas Robert machine that makes paper by a continuous process instead of one sheet at a time. Their version is so successful that a continuous web paper making machine is still called a Fourdrinier in English. *See also* 1798 MATR.

※ Physics

Thomas Young introduces the physical concept of energy and is the first to use the word *energy* with its present meaning in physics. *See also* 1842 PHY.

Hans Christian Oersted announces that he is looking for a connection between electricity and magnetism. *See also* 1819 PHY.

→ Transportation

Robert Fulton's *North River Steam Boat* is tested in the East River off New York City on

August 9; later renamed the *Clermont*, it makes its maiden voyage from Manhattan to Clermont, New York, on August 17. Although not the first steamboat, it is the first practical and economical one. *See also* 1803 TRAN; 1811 TRAN.

1808

★ Astronomy

Siméon-Denis Poisson [b. Pithiviers, France, June 21, 1781, d. Paris, April 25, 1840] publishes his work on perturbations of planetary orbits, small changes in orbits on one planet caused by the gravitational force of other planets. *See also* 1821 AST.

▷ Chemistry

Humphry Davy discovers the elements barium (Ba), strontium (Sr), and calcium (Ca) by electrolysis and infers the existence of magnesium (Mg), although pure magnesium will not be isolated until 1829. He codiscovers boron (B) with Joseph Louis Gay-Lussac and Louis-Jacques Thénard.

Joseph Louis Gay-Lussac announces on December 31 that gases combine chemically in definite proportions of vol-

umes. Previously it was only known that elements combine in definite proportions of masses (weights). *See also* 1805 CHEM.

Joseph-Louis Proust identifies three sugars in plant juices: glucose, fructose, and sucrose. *See also* 1811 CHEM.

↳ Communication

Friedrich Arnold Brockhaus [b. Dormund (Germany), May 4, 1772, d. Leipzig, Germany, August 20, 1823] purchases the rights to *Conversations-Lexicon*, now known as *Der Grosse Brockhaus*. He will complete the first edition in 1811 and later edit the second edition. Brockhaus will leave the project to his sons, who will carry on the encyclopedia throughout the 19th century. *See also* 1796 COMM.

Johann Strixner [b. 1782, d. 1855] and Ferdinand Piloty [b. 1786, d. 1844] in Munich produce the first color lithographs. *See also* 1798 COMM.

❖ Materials

To demonstrate the importance of iron to the Industrial Age, John Wilkinson is buried, as he had previously arranged, in an iron coffin.

♥ Medicine & health

Johann Christian Reil coins the term *psychiatry*. *See also* 1803 MED; 1812 MED.

※ Physics

Etienne-Louis Malus [b. Paris, June 23, 1775, d. Paris, February 24, 1812] discovers that reflected light that passes through Iceland spar does not show double refraction. Based on his explanation on an incorrect idea of Newton that light has two poles like a magnet, he suggests that only one pole has been reflected and introduces the term *polarization* to describe the phenomenon. *See also* 1669 PHY; 1809 PHY.

→ Transportation

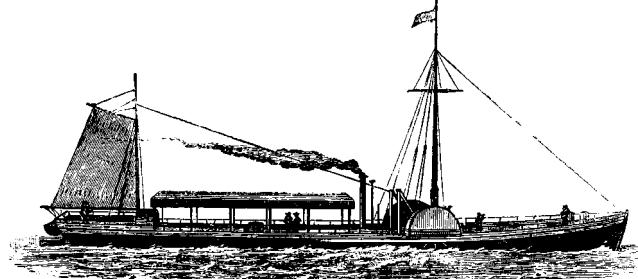
George Cayley builds a glider, which he called the Governable Parashute. His coachman becomes the first person to fly in a machine heavier than air, traveling some 275 m (900 ft). *See also* 1804 TRAN; 1877 TRAN.

Richard Trevithick builds a circular passenger railway on Gower Street in North London. Although the engine runs off the rails and crashes before a public showing promised for October, various persons pick up an admission ticket and go for a ride in July and August before the crash, reaching speeds of 20-km (12-mi) an hour. *See also* 1804 TRAN.

1809

↗ Biology

Jean-Baptiste Lamarck's *Philosophie zoologique* states his view that animals evolved from simpler forms, although the mechanisms he proposes for evolution are vague and,



ROBERT FULTON'S STEAMBOAT CLERMONT The *Clermont* was 46 m (150 ft) long and moved under steam at a brisk 8 km (5 mi) per hour—about as fast as a person jogs. The pair of paddle wheels near the mainmast makes this a "side-wheeler."

where more specific, later disproved on the basis of experiment. For example, Lamarck supports the discredited inheritance of acquired characteristics. *See also* 1801 BIO; 1858 BIO.

Communication

Joseph Bramah develops and patents a machine that cuts a goose quill into a dozen or so parts that can be slipped into a holder, where each part functions as a pen, replacing the entire goose quill. This device is successfully marketed and familiarizes the public with pens that combine a point (nib) and a holder. *See also* 600 COMM; 1822 COMM.

Samuel von Sömmerring [b. Thorn, West Prussia, (Germany), January 25, 1755, d. Frankfurt, Germany, March 2, 1830] builds a telegraph that uses electrolysis for detecting electrically transmitted signals. He has 35 wires lead to a tank, one for each letter of the German alphabet, plus one for each digit. The wires that produce bubbles when a current is sent through them indicate the letters. *See also* 1796 COMM.

Construction

The first Western suspension bridge capable of carrying vehicles, with a span of 74 m (244 ft), is built across the Merrimack River at Newburyport, Massachusetts. *See also* 1796 CONS; 1822 CONS.

Earth science

William Maclure publishes the first geological survey of the eastern United States. *See also* 1746 EAR; 1811 EAR.

Energy

Humphry Davy uses a high-

powered battery to induce a bright light between two strips of charcoal 10 cm (4 in.) apart, the first arc light. While it produces a great deal of smoke and heat, it also produces a brilliant bright light so long as the two carbon rods can be kept the proper distance apart. Arc lights come into general use in the 1870s. *See also* 1845 ENER.

Food & agriculture

Nicolas Appert, described by the February 10, 1809, *Courier de l'Europe* as “making the seasons stand still” with his canning process, wins the 12,000-franc award for his method for preserving food with his invention of canning and sterilizing food in glass jars. The prize is awarded January 10, 1810. *See also* 1804 FOOD; 1810 FOOD.

Mathematics

Gauss's *Theory motus corporum coelestium in sectionibus conicis solem ambientium* (“theory of the motion in conic sections of the heavenly bodies about the Sun”) includes Gauss's method of least squares for minimizing errors in calculations.

Physics

Ernst Chladni introduces sand figures (Chladni figures), obtained by sprinkling sand on vibrating metal sheets, to demonstrate the sound vibrations of solid objects. *See also* 1787 PHY.

Dominique François Arago [b. Estagel, France, February 26, 1786, d. Paris, October 2, 1853] discovers that the blue sky is polarized. He finds the neutral point (where polarization is absent), which is

named after him. *See also* 1808 PHY; 1811 PHY.

Transportation

George Cayley states the essential principles required for any flying machine that weighs more than the air it displaces. *See also* 1808 TRAN; 1843 TRAN.

1810

Biology

William Wollaston investigates Francesco Grimaldi's 17th-century discovery of sounds made by muscles by running a carriage over London streets until the pitch of its rumble is the same as that of the muscles. He concludes that human muscles all have a frequency of about 23 beats per second.

Chemistry

Augustin Jean Fresnel [b. Broglie, France, May 10, 1788, d. Paris, July 14, 1827] develops a method of making soda (sodium carbonate) using limestone and common salt. *See also* 1783 CHEM; 1835 MATR.

Communication

The University of Berlin is founded. It is the first university in which the goal of research is more important than education. Most teaching is done via large lectures or in small seminars of advanced students. Berlin and other universities modeled on it will put Germany ahead in science during the 19th century.

Russian-German physicist Thomas Johann Seebeck [b. Revel, (Estonia), April 9, 1770, d. Berlin, December 10, 1831] writes to Goethe that silver

chloride exposed to light of a particular color tends to take on the color of the incident light. *See also* 1802 COMM; 1891 COMM.

Energy

A steam engine built for operating a winch at a coal pit at Farme Colliery in Rutherglen, Scotland, will become one of the few steam engines from this time to remain in use in the 20th century. It will be decommissioned in 1915.

Food & agriculture

The mowing machine for hay is invented in the United States. *See also* 1784 FOOD.

In Pittsburgh, Pennsylvania, American inventor Oliver Evans builds the first mechanized flour mill in the United States to be powered by steam. *See also* 1783 FOOD; 1834 FOOD.

James Watt builds a demonstration flour mill powered by steam at Albion Mills. *See also* 1790 ENER; 1834 FOOD.

Nicolas Appert's *Le livre de tous les ménages, ou l'art de conserver pendant plusieurs années toutes les substances animales et végétales* (“art of preserving animal and vegetable substances for several years”) explains heat sterilization of food. *See also* 1809 FOOD; 1819 FOOD.

English merchant Peter Durand patents food preservation in cans made of iron, but mysteriously fails to provide any way to open them. *See also* 1809 FOOD; 1839 FOOD.

Mathematics

Joseph-Diaz Gergonne [b. Nancy, France, June 19, 1771, d.

Montpellier, France, May 4, 1859] starts the *Annales de mathématiques pures et appliquées*, the first privately established mathematics journal. *See also* 1797 CHEM; 1818 COMM.

Jean-Baptiste Joseph, Baron Fourier [b. Auxerre, France, March 21, 1768, d. Paris, May 16, 1830] presents his results on representing functions by infinite trigonometric series to the French Academy. The method of approximating any smooth curve by the sums of sine and cosine functions becomes important in many practical applications largely because both the sine and cosine are easily handled by calculus. *See also* 1811 PHY.

About this time, (Marie-) Sophie Germain [b. Paris, April 1, 1776, d. Paris, June 27, 1831], nicknamed the Hypatia of the 19th century, proves in correspondence with Gauss that Fermat's "last theorem" is true for odd-prime exponents less than 100 that do not divide the product xyz , where p is the prime and $x^p + y^p = z^p$. *See also* 1770 MATH; 1825 MATH.

♥ Medicine & health

Franz Joseph Gall, founder of phrenology, presents his theory that bumps on the head indicate character in volumes 2 to 4 of *Anatomie et physiologie du système nerveux en général*, which begins publication in this year but is not completed until 1819. *See also* 1805 MED.

Organon of Rational Healing by Christian Friedrich (Samuel) Hahnemann [b. Meissen, (Germany), April 10, 1755, d. Paris, July 2, 1843] introduces homeopathy, an alternative approach to medi-

cine that emphasizes that "likes are cured by likes" (for example, a medicine should produce the same symptoms as the disease) and that medicines should be given in extremely diluted forms. *See also* 1811 MED.

✿ Physics

Johann Wolfgang Goethe's *Zur Farbenlehre* ("on the theory of color") rejects Newton's theory that white light is a mixture of colors and contains a theory of color that is psychologically oriented and a revival of Aristotle's view. *See also* 1704 PHY.

I Tools

Marc Isambard Brunel applies his theories of mass production, previously exercised in the Portsmouth Shipyards, to manufacturing footwear for the British army. *See also* 1803 TOOL.

The Cotton Spinners' Association of Manchester, England, organizes one of the first strikes of the Industrial Revolution. *See also* 1742 TOOL; 1812 TOOL.

↗ Transportation

In France the 100-km-long (60-mi-long) St. Quentin Canal, with three tunnels, opens. *See also* 1805 TRAN.

English artist Thomas Walker

publishes *Treatise upon the Art of Flying by Mechanical Means*. *See also* 1808 TRAN.

1811

★ Astronomy

William Herschel formulates his theory of development of stars from nebulae, occasioned by his November 13, 1790, observation of a planetary nebula, NGC 1514, with a star embedded in it. Herschel believes that clouds of gas collapse into clusters of stars, which themselves collapse, creating an explosion that results in clouds of gas. Although the general outline of this theory is still believed to be true, the specific application to planetary nebulae is not accurate since it is the expulsion of matter from a single star (rather than from a cluster) that is now believed to cause these nebulae. *See also* 1790 AST.

◊ Chemistry

Amedeo Avogadro proposes that equal volumes of any gas at any given temperature and pressure always contain equal numbers of molecules (now known as Avogadro's law). *See also* 1799 CHEM; 1819 CHEM.

Jöns Jakob Berzelius introduces a system of chemical symbols that forms the basis of the system used today.

Bernard Courtois [b. Dijon, France, February 8, 1777, d. Paris, September 27, 1838] discovers the element iodine (I) in seaweed, but is not a sufficiently good chemist to recognize it as a new element. Iodine will be recognized as an element by Humphry Davy in 1814. *See also* 1818 MED.

German-Russian chemist Gottlieb Sigismund Constantin Kirchhof [b. Teterow, Mecklenburg-Schwerin, (Germany), February 19, 1764, d. St. Petersburg, Russia, February 14, 1833] prepares glucose by heating starch with sulfuric acid. *See also* 1808 CHEM.

Louis-Nicolas Vauquelin discovers uric acid in the excrement of birds.

■ Construction

The Standedge Tunnel between Marsden and Diggle in England is opened for traffic on April 4 after 15 years of digging. At 4984 m (5451 yd) it is the longest tunnel excavated to this time. *See also* 1843 CONS.

⊕ Earth science

Mary Anning [b. Lyme Regis, England, May 21, 1799, d. March 9, 1847], 12 years old at the time, discovers the 10-m-(30-ft-) long fossil of an ichthyosaur, the first such fossil known. *See also* 1821 EAR.

Amedeo Avogadro, Comte de Quarenga

[b. Turin, Piedmont (Italy), August 9, 1776, d. Turin, July 9, 1856]

In 1811 Avogadro proposed that equal volumes of gas at the same temperature and pressure contain the same number of molecules. Avogadro himself coined the word "molecule" to mean the smallest part of a compound. On the basis of his law Avogadro became the first to show that water is H_2O — that is, composed of molecules of two atoms of hydrogen and one of oxygen. The related concept, called Avogadro's number, is that when the mass of a compound in grams is equal to the molecular weight, the total number of molecules is always the same, equal to 1 mole.



A series of earthquakes centered around New Madrid, Missouri, continuing into 1812, devastates much of the poorly settled American Midwest. Estimated at about 8 on the Richter scale, these earthquakes are considered the most powerful in U.S. history because of the wide region affected. *See also* 1755 EAR.

Georges Cuvier and mineralogist Alexandre Brongniart [b. Paris, February 5, 1770] publish a geological map of the region around Paris. *See also* 1809 EAR; 1815 EAR.

The *Transactions of the Geological Society of London* starts publication.

❖ Energy

Freiberg, in Saxony (Germany), is the first city to be illuminated by gas light. *See also* 350 CE ENER; 1812 ENER.

Arthur Woolf compares the performance of his compound steam engine to the Watt engine and finds that it uses 50 percent less fuel than the Watt engine. *See also* 1804 ENER.

♥ Medicine & health

New Anatomy of the Brain by anatomist and surgeon Charles Bell discusses the difference between sensory and motor nerves and contains the law named after him, stating that the anterior spinal roots

are motor and the posterior roots are sensory. *See also* 1822 MED.

Samuel Hahnemann publishes a catalog of homeopathic drugs. *See also* 1810 MED.

✿ Physics

Dominique François Arago discovers the optical activity of quartz. *See also* 1809 PHY.

Siméon-Denis Poisson develops a mathematical theory of heat based on the work of Jean-Baptiste Fourier. *See also* 1810 MATH.

I Tools

American John Hall patents a breech-loading rifle, which he will begin manufacturing in 1820.

The German inventors Friedrich Koenig [b. Eislenben, (Germany), April 17, 1774, d. Würzburg, Germany, January 17, 1833] and Andreas Friedrich Bauer [b. Stuttgart, (Germany), August 18, 1783, d. 1860] build in London the first mechanical printing press. It prints 3000 sheets per hour and is used to print the *London Times*. *See also* 1814 COMM.

Geometer Jean Nicolas Pierre Hachette [b. Ardennes, France, May 6, 1769, d. Paris, January 16, 1834] publishes his theory of machine elements (simple machines) in *Traité élémentaire des machines* (“elementary treatise of machines”), in which he classifies machine elements according to their functions, thus laying the foundation for the systematization of mechanical engineering. *See also* 1782 ENER.

Georges Cuvier identifies from a drawing of the fossil the first known pterosaur, the pterodactyl.

❖ Energy

The National Light and Heat Company changes its name to the Gas Light and Coke Company when Samuel Clegg joins the firm started by Frederick Winsor. With Clegg's technical knowledge and Winsor's promotional ability, the company succeeds in lighting the city of London by coal gas over the next quarter century. *See also* 1811 ENER; 1816 ENER.

II Food & agriculture

Maize, known in the United States as corn, is hybridized successfully for the first time when two strains are cross-bred. *See also* 1724 FOOD.

Σ Mathematics

Pierre-Simon Laplace's *Théorie analytique des probabilités* (“analytic probability theory”) is a complete account of probability theory but little further work in the subject is done for three-quarters of a century. The book is based on advanced calculus and rescues work by Buffon, Bayes, and others that had been neglected. It also introduces a useful technique for solving differential equations, now called the Laplace transform. *See also* 1785 MATH; 1814 MATH.

♥ Medicine & health

Benjamin Rush's *Medical Inquiries and Observations upon the Diseases of the Mind* contains one of the first modern attempts to explain mental disorders. *See also* 1803 MED; 1845 MED.



Charles Bell

[b. Edinburgh, Scotland, November 1774, d. Worcestershire, England, April 28, 1842]

A pioneer in the study of the human nervous system, Bell discovered that nerves are actually bundles of fibers, each with its own origin. He showed that some nerve fibers have sensory functions and others have motor functions. Bell's palsy, a paralysis or weakness of muscles controlled by the facial nerve, is named after him.

⌘ Physics

Dominique François Arago builds a polarization filter from a pile of glass sheets. *See also* 1811 PHY; 1814 PHY.

I Tools

John Stevens of Hoboken, New Jersey, proposes a revolving gun turret for ships, but the idea is not developed as a practical matter until about 50 years later. *See also* 1835 TOOL.

Organized gangs in the North and Midlands region of England, called Luddites, smash mechanized looms and other textile-manufacturing equipment. In response, the British Parliament decrees that destroying or sabotaging machines will be punishable by execution. The group is named (it is said) after a Midland's apprentice, Ned Ludd, who after a beating by his supervisors took a hammer to a loom. *See also* 1810 TOOL; 1813 TOOL.

1813

⌘ Biology

Swiss-French botanist Augustin de Candolle [b. Geneva, Switzerland, February 4, 1778, d. Geneva, September 9, 1841] introduces the word *taxonomy* in his lifelong project of a 21-volume plant encyclopedia;

seven volumes are published during his lifetime, while the remainder are seen through the press by his son.

I Tools

William Horrocks [b. 1776, d. 1849] improves the power loom by introducing a system for varying the speed of the batten (the movable board that pushes the threads into place). *See also* 1846 TOOL.

In January the Luddite movement is smashed by English troops and magistrates with greatly expanded powers; 17 of the Luddite leaders are hanged. *See also* 1812 TOOL.

1814

★ Astronomy

Joseph von Fraunhofer makes his first detailed map of the solar spectrum, showing many lines. *See also* 1802 AST; 1815 AST.

◊ Chemistry

André-Marie Ampère suggests, as did Avogadro earlier, that equal volumes of any gas contain the same numbers of particles. *See also* 1811 CHEM.

⌚ Communication

The *Times* in London is printed by a steam-driven cylinder

press that prints 1000 sheets per hour. *See also* 1811 TOOL; 1847 COMM.

Σ Mathematics

Pierre-Simon Laplace's *Essai philosophique sur les probabilités* ("philosophical essay on probabilities"), which is the introduction to the second edition of *Théorie analytique des probabilités* ("analytic theory of probabilities"), contains his calculation of the mathematical expectation of sunrise based on the assumption that the Sun has risen each day for the past 5000 years. It also proposes that exact knowledge of the state of the world at a given moment allows the complete determination of all future states. *See also* 1812 MATH.

Mémoire sur l'intégration ("notes on integration") by André-Marie Ampère concerns various means of integrating partial differential equations. *See also* 1747 MATH; 1874 MATH.

⌘ Physics

David Brewster [b. Jedburgh, Scotland, December 11, 1781, knighted 1831, d. Allerly, Scotland, February 10, 1868] discovers the law named after him that gives the relationship between the index of refrac-

tion and the angle of incidence at which light reflected becomes completely polarized. *See also* 1812 PHY; 1815 PHY.

I Tools

The circular saw, developed in England, is introduced in the United States. *See also* 1869 TOOL.

✈ Transportation

British engineer George Stephenson [b. Wylam, England, June 9, 1781, d. Chesterfield, England, August 12, 1848] introduces his first steam locomotive, named Blucher, on July 25. It is capable of hauling 30 tons at speeds faster than a horse-drawn system can accomplish. *See also* 1808 TRAN; 1825 TRAN.

1815

★ Astronomy

Joseph von Fraunhofer makes a more detailed map of the solar spectrum that contains 324 lines. *See also* 1814 AST; 1820 AST.

⌘ Biology

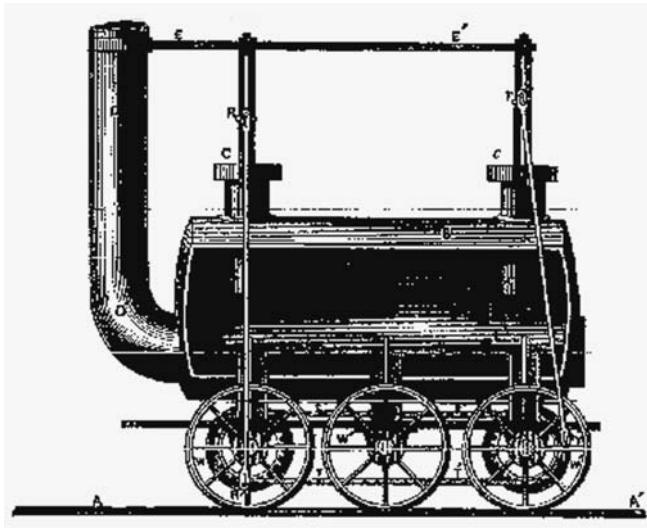
Jean-Baptiste Lamarck's *Histoire naturelle des animaux sans vertèbres* ("natural history of invertebrates") contains a number of new elements in animal classification; the work will be



André-Marie Ampère

[b. Lyon, France, January 20, 1775, d. Marseilles, France, June 10, 1836]

Ampère was the first to recognize that there is a direction for the flow of an electric current and to introduce a convention for determining that direction. He showed that wires carrying electric currents attract and repel each other magnetically. The amount of magnetism reflects the strength of the current. In 1827 Ampère he put his discoveries into the mathematical form known as Ampère's law: The magnetic force generated between two current-carrying wires varies directly with the product of their currents and inversely with the square of the distance between the wires. Ampère was one of the first to show that when current flows through a wire coiled into a helix, or three-dimensional spiral, the wire behaves like a bar magnet. This property later fueled many of the inventions of the age of electricity, including the telegraph, electric motor, and telephone.



GEORGE STEPHENSON'S SECOND LOCOMOTIVE A year after his first locomotive, Stephenson designed an improved version. The steam boiler and cylinders were essentially the same as on Blucher, but connections to the wheels were improved. Also, a system forced air onto the fire, doubling the power output, and a small steam-filled cylinder was installed above each wheel as a shock absorber.

completed in 1822. It is the first work to distinguish between vertebrates and invertebrates. *See also* 1801 BIO; 1817 BIO.

Earth science

The volcano Mount Tambora on Sumbawa (Indonesia) explodes on April 7, killing 12,000 people and sending enough dust into the air to lower temperatures for about a year, producing the “year without a summer” in New England in 1816. *See also* 1783 EAR; 1883 EAR.

William Smith’s *The Geological Map of England* is the first book to identify rock strata on the basis of fossils, enabling geologists far distant from each other to know that they are working with the same time period. *See also* 1794 EAR; 1816 EAR.

Food & agriculture

English landowners influence Parliament to pass the Corn Laws, restricting imports of grain and maintaining high prices; manufacturers soon learn that they have to raise wages or their workers will starve.

Mathematics

The Analytical Society, devoted to reforming British mathematics along Continental lines, begins meeting at Cambridge.

Medicine & health

Auguste Taveau introduces the use of an amalgam of silver and mercury for plugging cavities in teeth (dissolving silver coins in mercury to make the fillings). However, it does not become a common practice because of fears that poisonous mercury may leak from the amalgam. *See also* 1895 MED.

Physics

Augustin Louis Baron Cauchy [b. Paris, August 21, 1789, d. Sceaux, France, May 23 1857] presents to the French Academy his formulas for describing turbulence. *See also* 1921 PHY.

William Prout [b. Gloucestershire, England, January 15, 1785, d. London, April 9, 1850] claims that specific gravities of atomic species are integral multiples of the value for hydrogen. This would suggest that the known chemical elements were formed from hydrogen atoms. *See also* 1808 CHEM; 1865 CHEM.

Jean Baptiste Biot discovers the circular polarization of light. He also discovers the optical activity (rotation of polarization plane) in fluids, such as turpentine, and the strong dichromism in tourmaline (different colors seen from two different axes of the crystal). *See also* 1814 PHY; 1816 PHY.

Tools

The first gas meters, known as “wet meters,” are introduced for measuring consumption of natural or coal gas. They will not be superseded by “dry meters” until about 100 years later.

Humphry Davy invents the safety lamp to be used in coal mines.

Transportation

The first warship powered by steam is built in the United States. *See also* 1811 TRAN.

Scottish engineer John Loudon McAdam [b. Ayrshire, Scotland, September 21, 1756, d. Moffat, Dumfriesshire, Scotland, November 26, 1836] invents paving roads with crushed rock. Although the name macadam is in his honor, he

did not use tar or asphalt as in modern macadamized roads.

1816

Archaeology

Archaeologist Giovanni Belzoni [b. Padua, Italy, November 15, 1778, d. Gato, Benin, December 3, 1823] arrives in Egypt. He removes a colossal stone head from the vicinity of Thebes and ships it to the British Museum. The statue is known as “the young Memnon,” although it is inscribed with the name Ramses II. Later scholars will determine that it is a bust of Amenhotep II, also known as Memnon. *See also* 1817 ARCH.

The British government purchases the Elgin Marbles from Lord Elgin; eventually they are displayed in the British Museum in London. *See also* 1801 ARCH.

Chemistry

Humphry Davy discovers the catalytic action of platinum. *See also* 1806 CHEM.

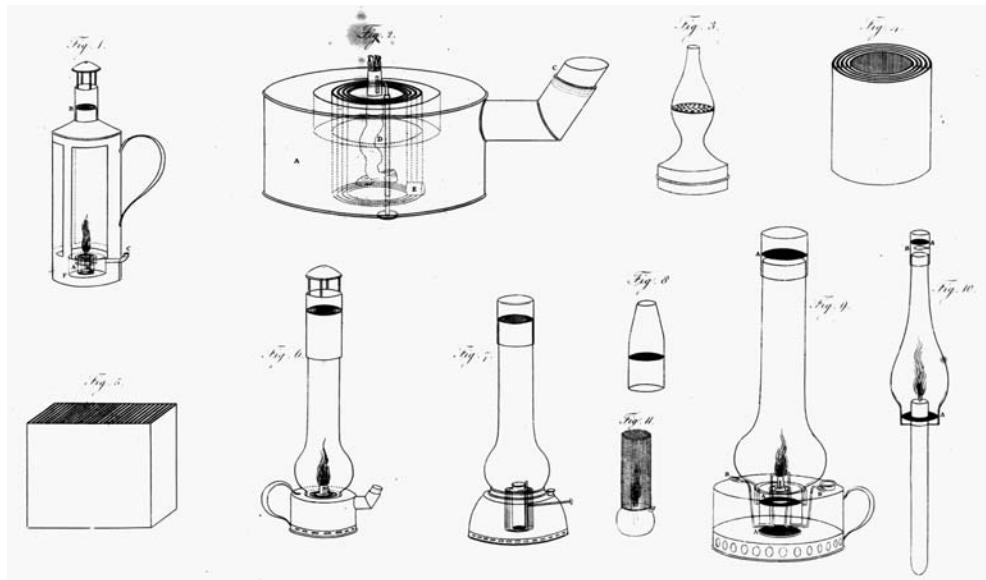
Communication

Joseph Nicéphore Niépce [b. Chalon, France, March 7, 1765, d. Saint-Loup-de-Varennes, France, July 5, 1833] begins experiments that lead to development of the first photographs. *See also* 1802 COMM; 1822 COMM.

German musician Johann Maelzel [b. 1772, d. 1838] patents the metronome.

Earth science

Lord Byron’s poem “Darkness,” written in June, describes his feelings in the “year without a summer” that follows the eruption of Tambora in 1815. *See also* 1815 EAR.



HUMPHRY DAVY'S SAFETY LAMP A society founded to help miners asked Sir Humphry Davy, famous and knighted for his discoveries of new elements, to solve the problem of mine explosions. His safety lamp is basically a simple flame protected by a wire mesh—shown here in various configurations. The mesh prevents the flame from reaching a temperature high enough to set off an explosion.

William Smith's *Strata Identified by Organized Fossils Containing Prints on Coloured Paper of the Most Characteristic Specimens in Each Strata* provides a list of characteristic fossils that can be used to identify rock strata. *See also* 1815 EAR; 1822 EAR.

Energy

William Wollaston improves the design of the voltaic cell by adding an apparatus to remove the copper and zinc plates from the acid when not in use, greatly extending the life of the cell. *See also* 1800 ENER; 1836 ENER.

Gas lighting is introduced in Baltimore, the first city in the United States to have its own plant for manufacturing coal gas for street illumination. *See also* 1812 ENER.

Medicine & health

René Laënnec invents the stethoscope. His first permanent stethoscope is a wooden tube about 23 cm (9 in.) long. *See also* 1801 MED; 1838 MED.

Physiologist François Magendie [b. Bordeaux, France, October 6, 1783, d. Seine-et-Oise, France, October 7, 1855] writes *Précis élémentaire de physiologie* ("an elementary summary of physiology"—two volumes with volume 2 published in 1817),

a textbook on physiology that introduces the importance of nitrogen in the diet and explains such processes as swallowing and vomiting. *See also* 1801 MED; 1838 MED.

Physics

Augustin Fresnel demonstrates with a specially constructed mirror experiment the wave nature of light and also gives an explanation of polarization. *See also* 1818 PHY.



(Théophile) René Laënnec

[b. Quimper, France, February 17, 1781, d. Brittany, France, August 13, 1826]

Doctors used to listen to a patient's heart by putting an ear to the chest. But Laënnec called this impractical and "hardly suitable where most women were concerned." One day in 1816, facing a plump woman complaining of heart problems, he rolled sheets of paper into a tube. He placed one end of the tube to his ear and the other end on the woman's chest. The sounds of her beating heart came through loud and clear. Laënnec called his invention a stethoscope, from Greek words meaning "to study the chest."

I Tools

David Brewster invents the kaleidoscope. *See also* 1847 COMM.

Marc Isambard Brunel invents and patents the round stocking frame, an improved mechanized knitting machine that can knit tubular fabric. *See also* 1758 TOOL; 1864 TOOL.

Transportation

Joseph Niepce improves the *célerifère*, which is renamed the *vélocifère*; although still not steerable and pushed by the feet, this ancestor of the bicycle becomes popular in Paris. *See also* 1790 TRAN; 1818 TRAN.

1817

Archaeology

In August Giovanni Belzoni uncovers the looted tomb of Pharaoh Ay, the successor to Tutankhamen, the first royal tomb to be excavated in modern times. In October he uncovers the tomb of Seti I, which contains an alabaster coffin and magnificent paintings on the walls and ceiling. *See also* 1816 ARCH; 1818 ARCH.

生物学

Russian zoologist Christian Pander [b. Riga, (Latvia), July 24, 1794, d. St. Petersburg, Russia, September 22, 1865] discovers the three different layers that form in the early development of the chick embryo. *See also* 1768 BIO; 1827 BIO.

Georges Cuvier's *Le règne animal distribué d'après son organisation* ("the animal kingdom, distributed according to its organization") gives an account of the whole animal kingdom, dividing it into four groups: vertebrates; a group containing arthropods and segmented worms; one containing bilaterally symmetrical invertebrates; and one consisting of invertebrates with radial symmetry. *See also* 1815 BIO; 1866 BIO.

French chemists Pierre Pelletier [b. Paris, March 22, 1788, d. Paris, July 19, 1842] and Joseph Bienaimé Caventou [b. Saint-Omer, France, June 30, 1795, d. Paris, May 5, 1877] isolate chlorophyll. *See also* 1804 BIO; 1837 BIO.

化学

German chemist Friederich Strohmeyer [b. Göttingen, Germany, August 2, 1776, d. Göttingen, August 18] discovers the element cadmium (Cd).

Johan August Arfvedson [b. Skagerholms, Sweden, January 12, 1792, d. Södermanland, Sweden, October 28, 1841] discovers lithium (Li), but fails to isolate it.

能源

Scottish vicar Robert Stirling [b. Cloag, Scotland, 1790, d. 1878] patents a hot-air motor that uses the expansion of heated air for driving a piston in a cylinder. Little interest

exists in the motor until about 1970, when companies such as Philips start investigating hot-air motors. *See also* 1805 ENER.

数学

Rein analytischer Beweis ("pure analytical proof") by Bernhard Bolzano [b. Prague, (Czech Republic), October 5, 1781, d. Prague, December 18, 1848] contains his proof of what we now call the Bolzano-Weierstrass theorem, the essential step in making analysis provable by turning it into arithmetic. Bolzano also defines a continuous function without using infinitesimals. *See also* 1822 MATH.

医学与健康

An Essay on the Shaking Palsy by James Parkinson [b. London, April 11, 1755, d. London, 1824] gives a clinical description of the disease that now bears his name.

工具

Richard Roberts [b. Wales, April 22, 1789, d. Manchester, England, March 16, 1864] builds one of the earliest planes for smoothing metal. *See also* 1800 TOOL.

1818

考古学

Giovanni Belzoni locates the entrance to the next-to-largest pyramid at Giza, lost even in ancient times. *See also* 1817 ARCH.

天文学

French astronomer Jean Louis Pons [b. Peyres, France, December 24, 1761, d. Florence, Italy, October 14, 1831] discovers Encke's comet, the comet with the shortest period on record. It

is named for Johann Encke [b. Hamburg, (Germany), September 23, 1791, d. Spandau, Germany, August 26, 1865], who calculated its orbit. Encke's comet has a period of 3.29 years and is still in orbit.

化学

Jöns Jakob Berzelius completes the discovery of lithium (Li) by separating out the pure element.

Pierre-Louis Dulong [b. Rouen, France, February 12, 1785, d. Paris, July 18, 1838] and Alexis Thérèse Petit [b. Vesoul, France, October 2, 1791, d. Paris, June 21, 1820] formulate the law named after them: In solid elements the product of the specific heat and the atomic mass is a constant. The Dulong-Petit law can be used to compute atomic masses. *See also* 1781 PHY; 1819 CHEM.

Louis-Jacques Thénard [b. La Loupière, France, May 4, 1777, d. Paris, June 21, 1857] accidentally discovers hydrogen peroxide.

Louis-Nicolas Vauquelin isolates cyanic acid. *See also* 1784 CHEM.

通信

Aloys Senefelder adapts his method of lithography to color printing. *See also* 1798 COMM; 1851 COMM.

地球科学

German-Swiss geologist Johann von Charpentier [b. Freiberg, Saxony (Germany), December 7, 1786, d. Bex, Switzerland, September 12, 1855] investigates an accident caused when a glacial dam bursts and kills many people. This leads to his recognition that Swiss glaciers formerly

were much more extensive and that large boulders, called erratics, had been moved by glaciers that no longer were present or no longer large. *See also* 1779 EAR; 1837 EAR.

医学与健康

French chemist Jean Baptiste André Dumas [b. Alais, France, July 14, 1800, d. Cannes, France, April 10, 1884] treats goiter, an enlarged thyroid, with iodine. *See also* 1811 CHEM; 1883 MED.

物理学

Augustin Fresnel's *Mémoire sur la diffraction de la lumière* ("notes on the diffraction of light") demonstrates that light is a transverse wave phenomenon. Fresnel's wave theory of light was at first strongly opposed, especially by Jean Baptiste Biot, but in time it was accepted by the scientific community. *See also* 1816 PHY.

工具

Eli Whitney invents the milling machine, which consists of a power-driven horizontal table that passes at a right angle under a rotating cutter. This is used by Whitney to make oddly shaped parts for muskets, but could also be used for making parts for many other devices. Whitney does not patent the machine, but freely shares it with government manufacturers of muskets. A case can be made that the milling machine was more important for U.S. industrial development than the more famous cotton gin — even English machinists imported or copied U.S. milling machines. *See also* 1817 TOOL; 1821 TOOL.

→ Transportation

Baron Karl Drais von Sauer-bronn [b. 1785, d. 1851] invents the *Draisienne*, the first type of primitive bicycle that can be steered; it has a padded seat. *See also* 1816 TRAN; 1839 TRAN.

1819

★ Astronomy

Dominique François Arago discovers that light from comet tails is polarized. *See also* 1809 PHY.

□ Chemistry

Eilhardt Mitscherlich [b. Oldenburg, (Germany), January 7, 1794, d. Schönberg, Germany, February 28, 1863] formulates his law of isomorphism, which states that chemical composition is related to crystalline form. *See also* 1811 CHEM; 1839 EAR.

British chemist John Kidd [b. London, September 10, 1775, d. Oxford, England, September 17, 1851] derives naphthalene from coal tar, the first of many important substances to be found in or made from coal tar. *See also* 1832 CHEM.

■ Food & agriculture

In this year and 1820 food preservation factories using the Appert process of canning in sterilized glass jars open in the United States, with Thomas Kensett's factory in New York City and William Underwood's in Boston, Massachusetts. *See also* 1810 FOOD; 1839 FOOD.

American inventor Jethro Wood [b. March 16, 1774, d. Ledyard, New York, September 18, 1834] of Scipio, New York, is granted a patent on a cast-iron plow with an improved moldboard

designed by Thomas Jefferson. It becomes the standard plow of the period. *See also* 1803 FOOD; 1833 FOOD.

Σ Mathematics

William George Horner [b. Bristol, England, 1786, d. Bath, England, September 22, 1837] develops Horner's rule for approximating the solution to equations. The same rule was known to the Arabs five centuries earlier. *See also* 1209 MATH.

♥ Medicine & health

René Laënnec's *Traité de l'auscultation médiate* ("treatise on mediate auscultation") treats the use of the stethoscope for investigating the lungs, heart, and liver. *See also* 1816 MED; 1826 MED.

⌘ Physics

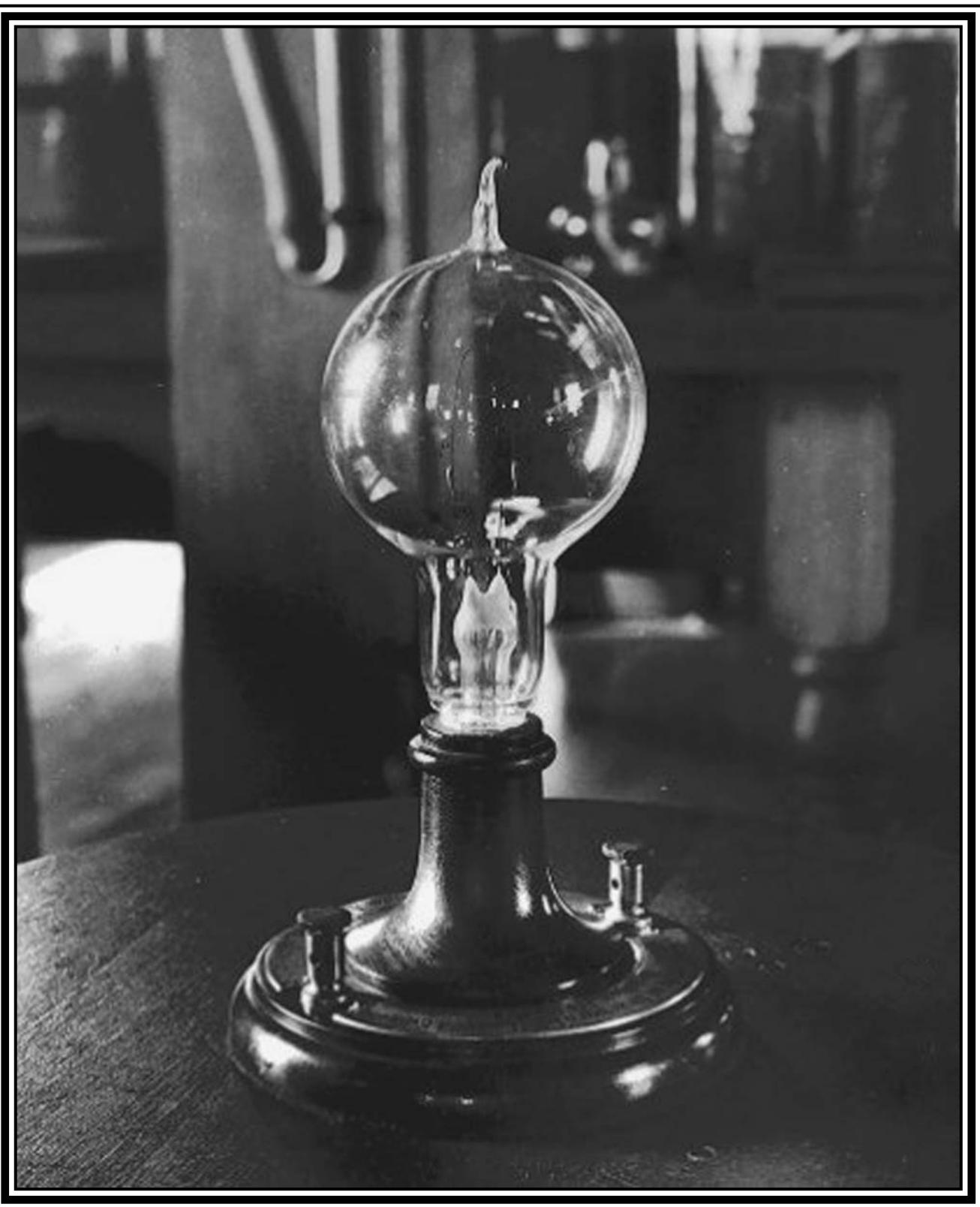
Hans Christian Oersted acci-

dently discovers that a magnetized needle is deflected by a nearby electric current (published in 1820). *See also* 1807 PHY; 1820 PHY.

→ Transportation

Joseph Francis [b. Boston, Massachusetts, March 12, 1801, d. Cooperstown, New York, May 10, 1893] develops an "unsinkable" lifeboat that uses hydrogen tanks for buoyancy and that has a self-bailing feature. *See also* 1838 TRAN.

The paddle steamer *Savannah* becomes the first steamship to cross the Atlantic (in 27 days 100 hours), although it is propelled by its sails 87 percent of the trip. It uses steam power for only 85 hours because of the small amount of coal the ship can carry. *See also* 1807 TRAN.



Science and Technology in the 19th Century: 1820 through 1894

Scientists in the 18th century had become increasingly fascinated with electricity, especially as better means of generating and storing it became available. Their work culminated in the voltaic pile, or battery, in 1800. Before this invention, electricity was only available for the brief moment of a discharge or as small amounts of static electricity. After 1800, scientists could work with an electric current. Even so, there was little progress toward understanding the nature of electricity until Hans Christian Oersted's accidental discovery, published in 1820, that electricity and magnetism are linked. As soon as word of this discovery spread, André-Marie Ampère, Dominique François Arago, and Michael Faraday began both to explain electricity and to try to put it to practical use. Indeed, Faraday had built the first prototype of the electric motor by 1821 and the first form of electric generator ten years later. It was not until late in the century, however, that practical applications became possible.

Much 19th-century science started with the discovery of electromagnetism, including Maxwell's mathematical laws that describe it (possibly the high point of 19th-century physical science), and with the relationship of electrolysis to chemistry. As the 20th century dawned, the more developed nations were utilizing the technological results of this scientific effort: electric motors, electric lights, the telegraph and telephone, the radio, and many other milestones.

At the end of the 19th century, work with cathode-ray tubes powered by an electric current led directly to the discovery of X rays and the electron and

indirectly to the discovery of natural radioactivity. The passage from electricity to electrons — or from Oersted in 1820 to Wilhelm Konrad Roentgen, J.J. Thomson, and Antoine Becquerel in 1895–97 — marks the true beginning of 20th-century science. That new era begins with the surprises of 1895.

Although the century can be characterized in terms of electricity — from electromagnetism to the dawn of the electron — there was equally valid progress in biology from the cell theory of 1838, evolutionary theory in 1858, Mendel's laws of heredity in 1860 and their rediscovery in 1900, and recognition of the importance of bacteria in the 1870s. But in both physics and biology, the long development of new ideas in the 19th century was just a prelude to their manifold applications in the 20th.

Science becomes professional

The 19th century was a period in which science and the teaching of science underwent a number of changes, giving it much of the form it has today. Science expanded enormously during the period and many of the new fields of science, such as anthropology, archaeology, cell biology, psychology, and organic chemistry originated during the first half of the century. Many other sciences, such as geology and chemistry, matured during the period.

During the 18th century, scientists who were not wealthy had to depend largely on patrons. There were no institutions that supported scientists, although there were a few teaching jobs and a little money could be made from books. This situation changed during

the 19th century as the occupation of scientist became a paid profession. This development first took place in Germany, where in a few decades the universities developed into centers where science flourished. Justus von Liebig set up his research laboratory for chemistry at the University of Giessen, initiating a trend that was soon followed at other universities. The teaching of science became linked to scientific research, a practice that later was followed by most of the universities in the world. The universities and scientific societies also started publishing scientific information, a development that was imitated in other countries. Scientific papers became important. In Germany, with Lorenz Oken taking the lead, scientists started meeting at national scientific congresses from 1822 on. First viewed with suspicion, these congresses later became instruments for increasing national unity in Germany. The exchange of scientific information between nations increased considerably.

National differences

France was the leading scientific country during the first decades of the 19th century, mainly through the impetus of Napoleon and the influence of the Ecole Polytechnique, the breeding ground for much scientific talent. In Germany during the 18th century, science was much less developed than in France or England and was still strongly influenced by mystical concepts from the Middle Ages and the Renaissance. Many of the great German scientists had to leave Germany for their education: Friedrich Wöhler went to Sweden

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to study with Jöns Jakob Berzelius, and Liebig went to Paris to study with Joseph Louis Gay-Lussac.

Germany, however, moved into the lead as the century progressed. While the French universities began to suffer from the French bureaucracy, teaching at German universities became more liberalized. Although the German universities were state controlled, the concept of academic freedom, the freedom of professors and students to choose their topics of study and research, became important and contributed to the strong development of science in Germany. The German term for science, *Wissenschaft*, is a broad term that includes all systematic knowledge, such as philosophy, philology, and history. This broad view encouraged an exchange among different scientific disciplines and also the development of entirely new fields, such as psychology.

The research style at the start of this period in England was similar to that of the 18th century and the number of scientists stayed relatively small. Science was the domain of a few talented individuals. Many scientists had no academic position. Training in science was generally lacking in England, although a large number of amateur associations of scientists existed. Several technical schools ("mechanic's institutes") were founded around the middle of the century. In some of them science teaching was more advanced than at the universities of Oxford or Cambridge, hampered by their connection to the Church of England, which required (in theory at least) that instructors be clergymen and that dissections not be practiced. By the end of the century, there were about a hundred times as many people enrolled in the various English scientific societies as there had been in the single Royal Society of the preceding century.

In Scotland the situation was somewhat different. The University of Edin-

burgh was not connected to the church; consequently, it was free to develop a medical school that became central to the scientific enterprise throughout Great Britain. Aspiring to a national identity, the Scottish universities developed quickly and established a tradition for learning that is still strong today. The Scottish universities attracted large numbers of students studying chemistry; but as professors' incomes were based on the number of students attending courses, the transition to practical classes and scientific research was made slowly.

In the United States, relatively little attention was given to science. The population in the United States grew steadily because of immigration, but the interests of the immigrants were largely oriented toward practical ventures rather than the pursuit of theoretical knowledge. The country excelled, however, in technology. Labor-saving devices were especially valued because of the comparatively low population density and the resulting high salaries for manual workers. Therefore the role of inventors and entrepreneurs in industrial development was large: Many major U.S. industries were founded by inventors such as Alexander Graham Bell, George Westinghouse, Thomas Edison, and George Eastman. In 1848 the American Association for the Advancement of Science was founded. It played an important role in the development of American science. But theoretical science remained in a secondary role in American education until well into the 20th century.

The philosophical basis of 19th-century science

During the beginning of the 19th century, especially in Germany, there was a romantic reaction against the mechanistic and materialistic philosophy behind scientific development. The

influence of Hegel, whose philosophy of nature was based not on experimentation but on *a priori* concepts, remained strong throughout the first half of the century in Germany. Scientists such as the great German poet Johann Wolfgang von Goethe tried to find scientific explanations by using general philosophical principles. For example, Goethe fought Isaac Newton's idea of white light being a mixture of colors, claiming that in principle white light should be simpler and purer in composition than colored light.

The idea that science would ultimately explain all phenomena in nature became stronger. The *Naturphilosophie* eventually lost influence and was replaced by materialism: *Kraft und Stoff* (force and matter) became the tenet of the new philosophical outlook. Matter and force, and later, matter and motion, were viewed as the ultimate explanations of reality.

The French philosopher Auguste Comte became the strongest spokesman of the philosophical school termed positivism. He viewed science as the most advanced stage of knowledge. In positivism the use of scientific principles to explain the laws governing all phenomena supersedes the two earlier stages of knowledge: a theological or imaginative stage in which phenomena are explained by divine powers, and a metaphysical or abstract stage in which phenomena are explained by general philosophical ideas.

Near the end of the century, Ernst Mach put forward ideas that were to have their most profound effect through their influence on Albert Einstein. He did not think a metaphysical stage was needed. Mach looked to sensation as the basis of all knowledge and was skeptical of attempts to establish cause and effect with certainty. His critique of Newtonian theory, because it is based in concepts of absolute time and space, was perhaps the most important

part of his philosophy for science. Initially he doubted that atoms could be real because they were not directly observable in the 19th century, but some think he eventually accepted that evidence could establish the reality of entities that could not be established on the basis of human sense.

The division between science and philosophy was not as clear in the 19th century as it is today. In Cambridge in 1883, William Whewell suggested to the British Association for the Advancement of Science that their members be called *scientists*, a term analogous to the word *artist* for those who practice the arts. Today we would call few of those members scientists, since most were amateurs or supporters of science. The word gradually caught on, however, and began to displace “natural philosopher.”

Part of the development of the concept of scientists and of a scientific method resulted from a change during the century in how students learned science. Laboratories were set up at the University of Edinburgh and, later, at other universities. William Thomson (later Lord Kelvin) was the first to have his physics students at the University of Glasgow conduct experiments. Experiments were clearly seen as science, while philosophy was thought to be based on pure reason.

Science and the public

Scientific thought was much more generally known than in previous periods, but for the first time it was opposed by segments of the public, especially those who held certain religious beliefs. This reaction was different from the official condemnation of Galileo by the church, which was essentially an institutional response, or Bishop George Berkeley’s criticism of Newton and Edmond Halley, an intellectual challenge. It also had little in common with the popular reaction against labor-sav-

ing technology of the 18th century. The 19th century saw general public criticism of some scientific ideas, along with newspaper cartoons and well-attended public meetings attacking specific theories.

The first issue to cause this kind of reaction was the age of Earth. Geologists offered good evidence that Earth is far older than most Christians, Jews, and Muslims at the time believed. Followers of these religions in the early 19th century expected Earth’s age to be about 6000 years, because 6000 years easily encompasses all the events of the Bible. Although Buddhists and Hindus believed Earth to be far older, they were not influential in science in Europe.

Opposition to an old Earth, however, was muted compared to the great reaction against the theory of evolution by natural selection proposed by Darwin and Alfred Wallace. People did not want to admit that humans were descendants, however long ago, of animals. The popular conception — never advocated by scientists — that humans’ immediate ancestors were monkeys was particularly the subject for ridicule. This controversy has continued to agitate some religious groups in the United States throughout the 20th century and into the 21st, although in the rest of the world the issue was settled in favor of evolution by the end of the 19th century.

Science and technology

The relationship between scientific education and technological progress became fully understood during the 19th century. Following the example of the Ecole Polytechnique in France, Germany and later the United States also founded technical schools with the idea of applying science to technology. At the end of the century, these technical universities played an essential role in the rapid expansion of industry. They developed the various kinds of engi-

neers who used science to solve technological problems rather than to advance knowledge.

At the end of the 18th century, discoveries by Antoine Lavoisier and Nicolas Leblanc in France had propelled a small chemical industry. But it was in Germany, which became the leading country in theoretical chemistry, that chemical research had the biggest impact on industry. By the end of the 19th century, the country had developed into the largest manufacturer of such chemicals as dyes, fertilizers, and acids used in industrial processes.

In biology, advances in microscopy led to the understanding of the role of cells and bacteria, concepts that previous scientists, for all their intelligence, could not have determined because of the inadequate range of the human eye. Similarly, the discoveries of the farther planets and their moons and the vast distances to stars depended on the bigger and better telescopes of the 19th century. Physics could not have reached the point of discovery of X rays (and soon after the electron) had it not been for a better vacuum pump that yielded various types of cathode-ray tubes. All in all technology advanced science even more than science improved technology; although the great advances of the 19th century — the telegraph and telephone especially — depended directly upon the scientists’ discovery of electromagnetism, taken here as the start of 19th-century science.

Major advances

ANTHROPOLOGY Anthropology began with a few glimmerings in the 18th century. When the first Neandertal remains appeared in 1856, however, there was still no context in which to put them. They were initially interpreted as recent. The peculiarities, or differences from a modern skeleton, were attributed to disease. Then, in 1859, Darwin’s theory of evolu-

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tion provided a theoretical context. Furthermore, Charles Lyell had already offered convincing arguments that the age of Earth is greater than most people thought. There was time for various precursor cultures of human beings to exist. The important 1879 discovery of cave paintings at Altamira in Spain was too spectacular for most people to believe. It was acceptable for early people to make primitive stone tools (after all, American Indians had used stone tools when they were first encountered). It was unacceptable for them to be great artists.

As time passed and Darwin's ideas gained influence, the idea of an ancestor to human beings took hold. For one thing, more Neandertal remains were discovered, making Neandertals a likely candidate as a different species of human. Furthermore, geological evidence suggested that some clearly human remains might be as old as 35,000 years. Eugène Dubois decided he would look for the "missing link" between people and the great apes. He believed that Java would be a good place to look, so he managed to get a job in Java. Astonishingly, he found the remains of a new species, closely related to modern humans, on the island.

At the end of the 19th century, despite these discoveries, physical anthropology was still not much of a science. It would gradually develop in the 20th century, joined by the even newer science of cultural anthropology.

ARCHAEOLOGY Around the same time as the start of anthropology, another closely related science came into being. Interest in archaeology, spurred in the second half of the 18th century by the excavation of Pompeii, increased after Napoleon's expedition to Egypt in 1798. Napoleon took scholars with him to study the antiquities known to be there. One of their discoveries, the Rosetta Stone, proved to be a seminal object. Jean Champollion in 1822 recognized that the stone contained the same inscription in two Greek scripts and in Egyptian hieroglyphics and was able to translate the previously untranslatable Egyptian inscriptions. Soon after, Georg Friedrich Grotefend and Henry Rawlinson translated the first texts in the cuneiform system used in Mesopotamia. Around the same time (1839), John Lloyd Stephens and Frederick Catherwood rediscovered the Maya civilization, the beginning of serious archaeology in the New World.

The most notable excavation of the century was the unearthing of many previously unknown tombs and temples in Egypt. Also notable was the discovery that the mounds of Iraq were actually such fabled cities of Mesopotamia as Nineveh and Ur. The most surprising find was Hermann Schliemann's excavation of Troy, which he followed with location of the ruins of the Mycenaean civilization.

In the New World, Ephraim George Squier moved from surveying the mounds of the Mississippi valley in the 1840s, to Central America in the 1850s, and finally to Peru in the 1870s, discovering previously unknown civilizations all along the way. In the last quarter of the 19th century, archaeologists became aware of the civilizations of the American Southwest.

ASTRONOMY Progress in the 19th century was marked by two technical discoveries that each did something unexpected. One was the discovery that light can be recorded by chemicals (in photographs) and the other was that light from different hot gases is different—so that, for example, one can tell the difference between hot hydrogen and hot sodium gas merely by examining



ALTAMIRA CAVE PAINTINGS When the remarkable paintings in Spain's Altamira Cave were first recognized by modern observers in the 19th century, few were willing to believe that the art was prehistoric. Later discoveries of similar paintings in French caves convinced the skeptics. Note the paintings of human hands, made by blowing pigment around a hand pressed against the cave wall. Such hand paintings are a common practice among early humans all over the world.

the light each gives off. The first discovery meant that astronomers no longer had to depend on looking through a telescope and recording what they saw in words or drawings. They could, instead, photograph what they saw. The second discovery meant that something that everyone thought to be completely impossible was in fact quite possible: A scientist could determine which elements are in a star. The two important new tools of photography and spectrography were eventually combined, and photography of stellar spectrums was routine by the end of the century.

Ancient astronomers had realized that the stars must be very far away, since they show no parallax (apparent movement as seen from the opposite ends of Earth's orbit) that could be measured in Antiquity. Indeed, the absence of measurable parallax was used as an argument that Earth does not move. Better instruments in the 19th century allowed Friedrich Bessel and others to use parallax, finding that stars are so far away that light takes years to reach Earth. This realization considerably expanded our understanding of the size of the universe.

Other discoveries were closer to home. Mathematics was the key in locating the eighth planet, Neptune, while careful observation at a propitious time helped Asaph Hall find the moons of Mars with a visual sighting. An excellent telescope at an excellent location helped Edward Barnard locate the fifth known moon of Jupiter. Since Barnard's discovery in 1892, all subsequent discoveries of planetary satellites have been made using photography or space probes.

A key change in the way observatories were sited affected astronomy at the end of the 19th century. Before 1887, telescopes were placed wherever it was convenient, usually in the vicinity of major cities. In 1887, the Lick Observatory was built on top of Cali-

fornia's Mount Hamilton, an inconvenient place that offered good viewing. Almost every optical observatory built since has been on a mountaintop.

BIOLOGY One of the great events in the history of science occurred when Darwin and Wallace presented the theory of evolution to the world in 1858. This was the watershed event in biology in the 19th century, but there were many other significant discoveries.

One was the development of the cell theory and the understanding of the importance of the chemistry of cells. Schleiden and Schwann proposed the cell theory for plants and animals in 1838–39. The technique of staining cells allowed biologists to begin to understand how the parts of a cell work.

Louis Pasteur made important advances in chemistry, biology, and medicine, many of them connected to each other. He showed that fermentation is not a purely chemical process, but one that is caused by yeast, and he convinced most biologists that spontaneous generation does not occur.

The borderline between chemistry and life was discovered late in the century as biologists realized that some agents of disease could pass through their finest filters. These unseen and unknown agents came to be known first as filterable viruses and later simply as viruses. Their exact nature would not be known until the 20th century.

Important advances in understanding heredity occurred during the century, but were not realized at the time. The most significant, Mendel's laws, were published but not noticed. They were rediscovered in 1900. Progress was also made toward discovering the mechanisms of heredity; but most of this progress can only be recognized in hindsight.

CHEMISTRY In some ways, chemistry is the archetypal 19th-century science. Chemists of the 18th century had paved the way for modern chemistry by

ridding themselves of phlogiston, discovering elements, and accepting the atom. In the 20th century, chemistry would be rethought in terms of physics. In the 19th century, however, chemistry held sway as the leading science.

Despite its preeminence, 19th-century chemistry was still an emerging science, with little understanding of why certain rules worked. For example, the concept of valence was introduced in 1852 and the periodic table in 1869, but it was not until the discovery of Wolfgang Pauli's exclusion principle in 1925 that either of these could be understood from first principles. The same holds true for another major advance, spectroscopy. With no understanding of how electrons behave — indeed, without any suspicion of electrons — the wonder of spectroscopy, identifying elements from the light they give off when heated, emerged without a theoretical basis. Chemistry is not alone in running ahead of its theories. A similar situation existed with gravity; for example, it was an enormously successful concept long before Albert Einstein explained its mechanism in the 20th century.

For a hit-or-miss science, however, chemistry had many more hits than misses. The atomic theory, first taken seriously by chemists at the beginning of the 19th century, gradually became accepted over the course of the century, although there were a few skeptics even into the 1900s. As early as 1824, chemists discovered isomers — compounds with the same chemical formulas but different molecular structures. By 1848 Pasteur had worked out the mechanism by which two otherwise identical isomers behave differently in living organisms. Organic chemistry became a part of the broader field of chemistry in 1848 when Wöhler synthesized the first organic compound from inorganic components. Within organic chemistry itself, the first work with dyes gradually led to an enormous

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chemical industry. Chemists also began to understand the structure of organic molecules.

COMMUNICATION At the beginning of the 18th century, the only way to communicate with anyone farther away than line of sight was to write a letter by hand and arrange to have it carried by a messenger. At the end of the 19th century, not only could you send a telegram across oceans and continents and converse over a telephone for shorter, but still substantial, distances, but you could also use the government mails to send a typed message or a reproducible recording. You could even mail a photograph, for photography developed during this same period.

Inventors were caught up in the progressive spirit of the age and thought that almost anything was possible — although Edison was genuinely surprised by his discovery of sound recording. Recording and reproducing sound was more unexpected than such fairly obvious applications of electromagnetism as the telegraph (practically everyone who learned about electricity seemed to think of a way it could be used to send signals) or such a slowly developing technology as photography. Surprisingly, the concepts of color photography and of television were implicit almost from the earliest days of chemical photography and the earliest experiments with sending messages over wires.

COMPUTERS Computation was gradually mechanized during the 19th century, starting with the first regular production of mechanical calculators in significant numbers and winding up with William Thomson's mechanical computer for solving differential equations (although not as advanced as Charles Babbage's prototype computer designs, it was actually built and used).

Mechanical calculators also would greatly simplify any scientific study that required computation — even though

such pioneering calculators as the Burroughs adding machine and the Comptometer were intended for business use.

The principal attempt at a computer during the 19th century did not get very far; however, it can be viewed from our vantage point as a singular effort. Charles Babbage designed a machine he called the Difference Engine in 1822 and even built a model of it. It was intended to calculate various functions automatically. But Babbage abandoned his Difference Engine in 1832 when he conceived the Analytical Engine, which we recognize today as a general-purpose mechanical computer. A working Analytical Engine was never achieved, but in 1890 an ingenious Herman Hollerith found a way to simplify handling the information from the U.S. Census based on punched cards. Hollerith later founded the company that was to become IBM.

CONSTRUCTION Domestic, ecclesiastical, and governmental buildings were built, but with little advance in technique. The great halls and fake castles of the time used earlier construction techniques to imitate those styles. The dominant building of the period, the factory, was seldom architecturally distinguished. Joseph Paxton's Crystal Palace in London in 1851, however, presaged techniques that would be used to build the first skyscrapers in Chicago, Illinois, starting in 1885.

The suspension bridge was pioneered as early as 1801 by James Finley in Pennsylvania and brought to Great Britain in 1825 by Thomas Telford, but it achieved dominance after the innovative techniques used to produce the graceful Brooklyn Bridge in New York City, opened in 1883.

As an alternative to a bridge, one could build a tunnel, with the first one under the Thames completed in 1843. Bridge and tunnel construction also led to significant studies of forces and the strength of materials. Pioneering work

by French engineers, especially those connected to the Ecole des Ponts et Chaussées ("school for bridges and highways"), led to better understanding of the mathematical side of engineering.

EARTH SCIENCE Geology moved from its tentative beginnings at the end of the 18th century to become a major science in the 19th century. In particular, Charles Lyell convinced many of the truth of James Hutton's view of the ancient history of Earth. In turn, Lyell influenced Darwin in the development of the theory of evolution. One of the major innovations that started with Lyell's work was the acceptance of a standard geologic time scale based largely on the presence of characteristic fossils in rock strata. Fossils had another important use during the period. Geologists beginning with William Smith realized that different assemblages of fossils could be used to date rock strata that were many kilometers apart. If the same groups of fossils were present, the rocks had to be about the same age. This tool was used to work out the geologic history of Earth and to identify such ages as the Devonian and Cambrian.

Major excitement came from discoveries of fossils, which were just beginning to be understood as the remains of species that no longer existed on Earth. The dinosaurs, first found and interpreted during this period, were especially exciting and prompted the rivalries of the bone hunters of the American West. As an explanation of the extinctions that clearly had taken place, Georges Cuvier proposed in 1825 that catastrophes had destroyed these early species. Darwin's view that small changes had removed some species superseded Cuvier's by the end of the period.

This is not to say that the catastrophe theory was rejected completely. Louis Agassiz promoted the idea that Earth had suffered an Ice Age, a concept that was gradually accepted as the century wore on and new evidence accumulated.

In fact, the 19th century had its own small catastrophe — the eruption and explosion of Krakatoa in what is now Indonesia, the major volcanic event of the period. It raised waves and colored sunsets around the world and was widely heralded as the loudest noise ever on Earth.

The seismometer, which records the various types of waves produced by an earthquake, was developed during the period. It would contribute to a much greater understanding of the interior of Earth in the 20th century.

ENERGY The first part of the 19th century was the golden age of the steam engine. But toward the end of this period, the 1870s produced virtually modern forms of the internal combustion engine, which would become the main sources of power for large machinery and transportation. The steam engine, powered mostly by coal, used a familiar source of energy. The main fuel for smaller internal combustion engines (after some experimentation with other forms) was a new chemical mixture, gasoline, while the larger diesels used a different product, petroleum.

The use of coal and coke for making steel or powering steam engines became commonplace, and thus technical-minded people became familiar with the gases produced during the manufacture of coke. These gases burn with a pale light. Rather than waste the gases, various enterprising inventors in Germany, France, and England experimented in the early years of the 19th century with coal-gas lighting for houses, factories, and city streets. Cities were being lit this way as early as 1811, and by 1820 the major cities of Europe were all partially illuminated. One name for the mid-19th century is the gas-light era, referring to the period of somewhat more than 50 years during which gas lighting was used on a large scale and before electric lights were introduced.

Although gas light is not so bright as

electric light, it is bright enough to extend the day beyond the natural dawn-to-dusk requirements of the human as a diurnal animal. Gas light also made it possible for large indoor structures to be used as factories. Before gas lighting, much work that we would now do indoors was conducted in the open, with small interior work-rooms for rainy-day labor adjacent to the work site. Eventually the gas-lit, and later the electric-lit, factories would lead to second and third shifts of workers, making better use of capital if not of human beings.

The development of current electricity had many consequences. To think that the force that attracted straw to amber that had been rubbed, the force that produced surprising "shocks" when a charged body was touched, the force just identified as present in lighting — that force! — could be produced in steady streams and transmitted by wires over considerable distances was truly astonishing. Chemical means of producing an electric current were first introduced at the very beginning of the 19th century, and various electric batteries have been made since. With a source of current for experiments, scientists began to discover that currents could also be produced mechanically. Most people by the mid-19th century had begun to see that electricity was the wave of the future (James Clerk Maxwell explained its wave nature in 1873). Electric power was already being applied in communication and some forms of lighting.

Although most of the 19th century was illuminated by coal gas (natural gas was not exploited for any purposes in the West to any extent until the 20th century despite a long tradition of use in China), experiments with electric lighting were ongoing throughout the century as well. It was not until 1858, however, when the first arc lamp was installed in a lighthouse, that practical electric lighting existed. Much better

arc lights were not invented and used until just before 1879, when the first long-burning incandescent lamps were constructed by Edison and Joseph Swan. After 1879 the electric light not only turned night into day, but the wires set up to power lights also brought electric power into homes and factories for other uses. Electricity would soon run small motors or heaters of all sorts and in the 20th and 21st centuries would become the power source for devices not even contemplated during the 19th.

Although we think of this as a time that began with waterpower and ended with the steam engine and electric motor, not all significant devices used engines for power. Hydraulics were employed for some machines, and there were a number of devices, some of which we still use, based on compressed air.

FOOD & AGRICULTURE New agricultural machines, fertilizers, and pesticides contributed to the ability of farmers to feed and clothe a growing population. Although the Chinese had developed several ways of fighting insect pests, practices in the West lagged behind. As chemistry began to develop, some new chemicals and some old ones began to be used in systematic ways as pesticides. Most of these were poisons to vertebrates as well as insects, but the first glimmers of pest-specific poisons were seen during this period. Perhaps because farmers were aware of the dangers of 19th-century pesticides to themselves and to other animals, use of pesticides was not so extensive as to pose a serious environmental hazard at this time.

Nearly all perishable foods can be refrigerated for longer shelf life with virtually no deterioration in taste, texture, or nutrition for days or even weeks. Artificial refrigeration, invented near the end of the 19th century, may not have been so unexpected an idea as

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the century's first preservation breakthrough, canning (since people knew that ice preserved food), invented at the beginning of the 19th century and becoming widespread during this period. Together, canning and refrigeration were truly revolutionary, for they directly improved the health of people all over the world. Although urban sanitation control is often cited as the main improvement in health and longevity of the past few centuries, certainly as important as immunization and antibiotics, the food preservation revolution (which has continued into the 20th century with frozen foods, freeze-dried foods, new forms of sterile packaging, and even food irradiation) merits the same recognition.

MATERIALS As noted in the discussion of chemistry above, the chemical industry arose during this century, especially in Germany. Essentially nonexistent at the start of the 19th century, the chemical industry was a major factor in society by its conclusion. Some results of this new industry include useful rubber products (erasers, fabrics, and, in 1839, vulcanized rubber), nitric acid (1838), and sodium bicarbonate (1861).

Although we think primarily of the coal-based chemicals and the inorganics during the 19th century, a separate revolution was beginning, based on plant and animal materials, mainly wood. The plastics industry got underway with celluloid, based like paper on cellulose from plants. Finally, there was an array of new explosives (nitrocellulose, nitroglycerin, and dynamite) that were built to some degree on plant (cellulose) or animal (glycerin) products.

Another major change in the use of materials came from new construction materials, which included Portland cement and the advent of cheap steel made by the Bessemer process. Closely connected to this was the use of steel in the new engines and machines that

were developed and in new construction techniques.

MATHEMATICS In England, the Analytical Society began a trend toward reviving mathematics that culminated in the first developments in abstract algebra before the end of the century. The society, started by undergraduates at Cambridge, was committed to bringing Continental mathematics to England. They recognized that almost no one in England could read or understand Continental mathematics, in part because the symbolism used was not the same.

The reform movement in analysis was an attempt to put the calculus of Newton and Leibniz and their followers on a logical basis. It was clear that the calculus (and the larger field of analysis, which includes calculus) worked, but it was not clear why. In the 1820s Augustin Louis Cauchy redefined the calculus without using infinitesimals or appeals to intuition. Later in the century, Karl Weierstrass, Richard Dedekind, Georg Cantor, and others worked to make analysis completely dependent on the arithmetic of natural numbers and their ratios, returning in a sense to the goals of the Pythagoreans. This effort is considered to have been successful by most mathematicians.

Notable achievements at the beginning of the period were the proof that quintics (polynomial equations of the fifth degree) cannot be solved by algebraic methods and the development of elliptic functions, both by Niels Abel, who died at 26 of tuberculosis. Elliptic functions have two periods, similar to trigonometric functions, which have one period.

Before the beginning of this period, Karl Friedrich Gauss had revived number theory and added considerably to it. His work became the basis for number theory during the rest of the 19th century. Gauss also developed new uses for differential equations, which

became a major topic of study during the century.

Early in the period, projective geometry emerged as a new variety of generalized geometry. It is concerned with the properties of figures that do not change when the figure is projected from one plane to another. It is, therefore, concerned with questions about the intersections of figures, but not with questions of measurement or parallelism, since measures are not preserved under projection.

Abstract systems, such as group theory, developed into whole branches of mathematics in their own right. At first mathematicians thought there might be some simple set of universal rules for numbers and numberlike entities. This view became untenable, however, when Sir William Rowan Hamilton realized in 1843 that there were numberlike entities of interest for which a times b does not necessarily equal b times a . Thereafter, algebra began increasingly to be concerned with sets of rules that describe specific structures, which came to be called rings and fields as well as groups. The study of such structures is termed abstract algebra.

A development related to abstract algebra and sometimes considered a part of it is Boolean algebra, a system developed by George Boole in 1854 for applying an algebraic system to the laws of thought. To some degree, however, Boolean algebra has been subsumed by two other major developments of the century, the rise of formal systems of symbolic logic and the creation of set theory. Although Boolean algebra is a formal symbolic logic, it was not used when Gottlob Frege and Giuseppe Peano began their attempts to find a logical basis for arithmetic. They created new symbolic logics for this purpose. Symbolic logic in the sense of Frege and Peano was to become vital in the development of the foundations of mathematics in the 20th century.

Set theory is almost purely the creation of Georg Cantor, although later mathematicians have axiomatized and expanded it. Set theory brought the actual infinite into mathematics for the first time. Since the time of the ancient Greeks, the infinite had been viewed in terms of potential — a line could be extended as far as one liked, a larger number could always be found, and so forth. Cantor found ways to consider such sets as the complete set of natural numbers or the complete set of points on a plane, sets that are completed infinities, not just potential ones. His work was not well accepted by his contemporaries, but it was extraordinarily influential in the 20th century. Basic operations with sets are similar to operations in Boolean algebra, although the symbolism is different.

MEDICINE & HEALTH While the 19th century was a period of steady progress in understanding how the human body works, the most significant advances of the period were the discovery of anesthetics and the articulation of the germ theory of disease with the related development of vaccines for diseases other than smallpox. Most authorities attribute today's longer life span primarily to improved sanitation. The main developments in the 19th century were the realization that contaminated water carries disease and that cleanliness is essential to surgery. Near the end of the period, the germ theory of disease explained both of these observations. Other progressive steps, such as the use of citrus fruit to prevent scurvy and vaccination to prevent smallpox, were found to work, but the rationale for them awaited scientific developments of the 20th century. Mental illness began to be looked at somewhat scientifically and treatments included hypnosis, new to science although probably known to shamans and traditional healers.

New tools for diagnosis included the ones most commonly used in a routine

examination today: thermometers suitable for taking body temperature, a stethoscope (first described in 1819) and thumping to listen to the heart and lungs, and several devices for measuring blood pressure. Dentists acquired the drill and became better at making and installing false teeth when the drill and various fillings, some invented during this period, failed to suffice. Familiar operations, such as the appendectomy and tracheotomy, were introduced.

In many ways, however, the greatest immediate benefit during the period was the introduction of general anesthesia, which made many of the other innovations possible. Doctors had known from ancient times that alcohol ingestion could have a pain-deadening effect, but alcohol is not suitable as a way to kill pain during surgical procedures. It is too slow, for one thing. For another, the amount needed to produce unconsciousness is close to the amount that can cause death. Much the same is true for the other early painkiller, opium. In the 1840s, doctors and dentists found three substances that worked much better than alcohol or opium: ether, nitrous oxide, and chloroform. Any of these anesthetics produces complete unconsciousness with no arousal by pain. Although all are dangerous, few patients were lost to the new anesthetics. With immobilized patients who felt no pain during the procedure, surgery could proceed toward developing the efficiency and delicacy that make it one of the most important branches of medicine today.

Previously, scientists believed that disease was caused by imbalances (the humoral theory of disease), bad air (the miasmal theory), or other conditions. The germ theory of disease replaced these ideas and formulated the concept that water supplies and air could transport disease, that doctors themselves could spread disease, and that certain small specific organisms could be

found in conjunction with specific diseases. Louis Pasteur and Robert Koch not only were able to explain and extend these ideas, they were also able to develop methods of immunization against some diseases. The germ theory became so entrenched by the end of the period that it was assumed even in cases where no disease-causing agent could be found, leading to the concept of filterable viruses.

Pasteur's success in producing immunity by vaccination is even more remarkable when one considers that the concept of an immune system was just being developed. In the 1880s Ilya Ilich Mechnikov discovered one aspect of the immune system. He found that white blood cells ingest and destroy foreign particles in the blood. Today we know that there are a host of different types of white blood cells, each with its own set of duties, forming the backbone of the immune system. Paul Ehrlich also studied white blood cells. He developed one of the first theories of antibodies near the end of the century.

Other important body systems just beginning to be understood in the 19th century were the two systems of hormones, the endocrine and the exocrine. In the 1820s and 1830s William Beaumont became the first person to study the digestive process in a living human when his patient Alexis St. Martin incurred a stomach wound that failed to close completely. Beaumont was able to perform a number of experiments on St. Martin that demonstrated that powerful chemicals in the stomach turn food into simpler substances. These chemicals are hormones of the exocrine system. Much later, in 1889, came the beginnings of knowledge of the endocrine system when it was observed that removal of a dog's pancreas produces symptoms of diabetes. Similarly, in 1894 it was found that ground-up adrenal glands produce physiological changes. Early in the 20th century these and sim-

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ilar observations were the bases of the development of the hormone theory.

PHYSICS As noted above, a major influence on both the science and technology of the 19th century was the discovery of the relationship between electricity and magnetism. Another thread that runs through the century is the science of heat, or thermodynamics. Thermodynamics was introduced as a concept as early as 1824 and its main laws worked out by 1865.

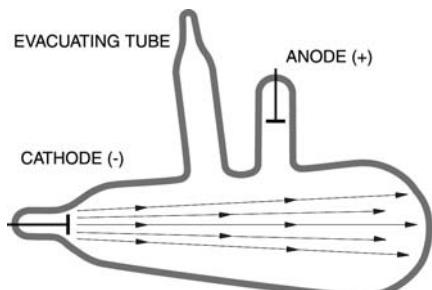
Often an important concept must be defined before progress can be made. Just as the concept of force was unclear before Newton's time, the concept of energy was unclear before the 19th century. Today children in elementary school are taught that a battery changes chemical energy to electrical energy or that friction changes the energy of motion (kinetic energy) to heat energy. These insights were made possible from 1842 through 1847 when Julius Mayer, James Prescott Joule, and Hermann von Helmholtz independently studied energy transformation and concluded that energy is not gained or lost as it is transformed from one type to another (the law of conservation of energy). By 1853 it was possible to relate these ideas to potential energy, such as the energy of position. The concept of energy was an essential prerequisite to Einstein's 1905 proof that energy and mass (matter) are two forms of the same thing.

The study of waves, especially light waves, also developed during the century, beginning with the discovery in 1842 of the Doppler effect: Waves produced by a moving source are raised in frequency (higher in pitch for sound waves) when the source is moving toward an observer and lowered when the source is moving away. In 1848 Armand Fizeau showed that the same effect occurs with light, implying that light from a source moving away from an observer will appear shifted to the red. Fizeau and Léon Foucault were able

to measure the velocity of light using other methods, but in 1881 Albert Michelson developed the interferometer, which measures slight changes in a wave by comparing two versions of the same wave. Not only could this new device measure the speed of light with greater accuracy than previous measurements, it could also use a form of the Doppler effect to determine the absolute motion of Earth through space — assuming that there is a stationary substance called ether pervading space. The negative conclusion of Michelson's measurement with Edward Morley in 1887 was not fully explained until Einstein's special relativity theory in 1905. In the meantime, James Clerk Maxwell's explanation of electromagnetism in terms of waves led to Heinrich Hertz's discovery of radio waves.

Toward the end of the century, many physicists began to experiment with the first vacuum tubes, based on the work of Heinrich Geissler, who developed the means of producing good vacuums starting in 1855. Using such a tube, the mathematician Julius Plücker discovered that rays could be produced in a vacuum tube. Named cathode rays by Eugen Goldstein in 1876, the rays were investigated extensively by William Crookes, who developed even better vacuums than Geissler had. Although Crookes came close to making fundamental discoveries with his Crookes tube, as it came to be known, others were to start the so-called second scientific revolution in 1895 based on discoveries made with the Crookes tube.

TOOLS Better and more destructive explosions were considered a sign of progress throughout the 19th century. In addition to the new explosives that were developed, cannons and cannon manufacture were greatly improved. The revolver was developed, but well before either the self-contained cartridge or the familiar bullet-shaped projectile. Military needs were behind



CROOKES TUBE The Crookes tube developed from earlier versions, all based on sending an electric current through a near vacuum. Such tubes—the predecessors of the cathode-ray tubes used for one type of television screen and computer monitor—were the tools that enabled two of the major discoveries of the late 1890s—the electron and X rays (which are produced when the electrons that stream from the cathode impact the glass wall of the tube).

most of these advances, although hunting with guns was still important.

With industrial progress came the need to measure both the environment and the output of the new devices. Over a dozen new measurement devices were developed, ranging from water and gas meters to at least five ways to measure electricity. Along with measurement, automatic safety devices came into use, including governors and safety valves. Despite all the measuring and safety innovations, however, steam engines and gas had an unhealthy way of blowing up throughout most of the 19th century.

TRANSPORTATION The steam engine soon became small enough that inventors could envision placing it on vehicles that it moved — self-propulsion. Ships were already adapted to carrying heavy loads and to being propelled by the wind. Steamships of various types proliferated in Europe and the United States, propelled by engines that shoved ships through the water by paddles or paddle wheels before the screw propeller was invented. Despite the importance of steamships for river travel — they could go upstream or down and did not have to rely on less certain

winds even at sea — economics promoted freight shipments across land by canal and by sail in the open ocean.

At the beginning of the century, the canal was still the best way to transport freight (the Erie Canal opened in 1824) and the steamboat was just beginning to replace sailing ships. But a year after the Erie Canal opened, the first practical locomotive service began. By 1869, railroads crossed North America and were ubiquitous in Europe.

The balloon had been invented in 1783, so it too became a target for self-propulsion by steam, especially after the

propeller was invented. Balloons, however, never became a major form of transportation. Another minor form of transport during this period — submarines and diving bells — went down instead of up. Effective submarines, however, had to await the development of a power source that did not depend on air.

At the very end of the Industrial Age, a new power source was about to revolutionize transportation. As early as 1859 Jean Lenoir had developed the first internal-combustion engine. By 1885 Karl Benz was driving the first automobile, the destined major form of

transportation of the 20th century. The internal-combustion engine would not only power the car, truck, and tractor, it would also turn flight from an occasional adventure into what many today regard as a necessity.

One modest means of propulsion made steady improvement from quite unpromising beginnings throughout this period. The bicycle has been steadily improved since its first introduction in the 18th century as a toy for aristocrats. In much of the world the bicycle even today is a more important means of personal transportation than the automobile.

CHRONICLE

1820

★ Astronomy

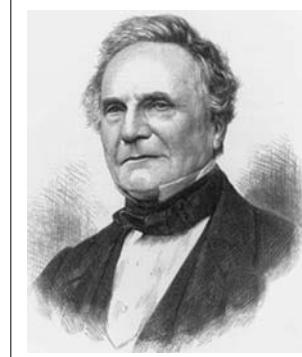
The Royal Astronomical Society is founded by, among others, inventor and mathematician Charles Babbage and astronomer Sir John Frederick Herschel [b. Slough, England, March 7, 1792, d. Collingwood, England, May 11, 1871]. See also 1660 COMM.

💻 Computers

French inventor Charles Xavier de Colmar [b. 1785, d. 1870] builds a mechanical desk calculator, called "Arithmomètre," based on the principles of the Leibniz computer of 1673. More than 1500 of such calculators will be sold during the next 30 years. See also 1774 COMP; 1889 COMP.

🏗 Construction

American architect Ithiel Town [b. Thompson, Connecticut, October 3, 1784, d. New Haven, Connecticut, June 13, 1844] invents the lattice truss for bridges, which strengthens bridges with two



Charles Babbage

[b. Teignmouth, England, December 26, 1792, d. London, October 18, 1871]

Babbage designed and partially built the first mechanical computers. In 1832 he built a demonstration model of his first advanced calculator, the Difference Engine, designed to compute logarithms and other functions. This model worked to some degree, and Babbage's plans were later used to create fully functioning versions. Babbage also designed a device he called the Analytical Engine. This was supposed to use punched cards as input for problem-solving programs and have the equivalent of memory and a central processing system, but it was never built. Babbage was the first to use mathematics to study a complex system (the English postal system); his ideas led to the flat-rate postage stamp. He was also an inventor credited with the first ophthalmoscope, speedometer, skeleton key, and cowcatcher for locomotives.

long horizontal beams laced together by a number of diagonal struts in a lattice pattern. See also 1805 CONS.

㊂ Earth science

Russian explorer Fabian Gottlieb von Bellingshausen [b. Arensburg on the island of Oesel, Russia, August 30, 1779, d. Kronstadt, Russia, January 25, 1852], American Nathaniel B. Palmer, and Englishman Edward Bransfield independently become the first humans known to sight the continent of Antarctica. See also 1844 EAR.

⚡ Energy

British astronomer Warren De

la Rue [b. Guernsey, Channel Islands, England, January 15, 1815, d. London, April 19, 1889] encloses a platinum coil in an evacuated glass tube and passes electricity through it in the first recorded attempt to produce an incandescent lamp. See also 1840 ENER.

🍴 Food & agriculture

Guano from South America, introduced by Alexander von Humboldt, becomes a widely used fertilizer in Europe. It is high in both nitrogen and phosphates, which will be discovered later in the 19th century to be essential to plant growth. See also 1802 FOOD; 1937 EAR.

The cultivator, a mechanical

device for removing weeds by turning over the top layer of soil (like a mechanical hoe), is invented in the United States. See also 1810 FOOD.

Σ Mathematics

Sir John Leslie's *Philosophy of Arithmetic* describes methods of calculating in any base with either signed or unsigned digits. See also 1720 MATH.

⚛ Physics

The science of electrodynamics is born with publication of Hans Christian Oersted's discovery of electromagnetism and André-Marie Ampère's continuing discoveries. See also 1819 PHY; 1824 PHY.

Electricity and magnetism

Although the ancient Greeks and probably earlier peoples knew about magnetism and static electricity, not much was accomplished with these interesting phenomena until the Chinese began to use the magnetic compass for navigation around 1000 CE. Some of the basic laws of magnets were written down in 1269 and William Gilbert studied both static electricity and magnetism at the end of the 16th century. Then the subject was ignored by most scientists for a long time.

In the 18th century, Stephen Grey and Charles François Du Fay revived the study of static electricity, but it was not until Pieter van Musschenbroek received the first powerful electric shock (apart from those caused by lightning) in 1745 that the subject gained attention. Van Musschenbroek was one of the inventors of the Leiden jar, a device for storing static electricity. A Leiden jar releases all of its electricity at once, causing a shock if it passes through a grounded person. Van Musschenbroek reported, "In a word, I thought it was all up with me" after his shocking experience. The discovery that electricity could cause powerful shocks prompted Benjamin Franklin's famous kite experiment, in which he showed that lightning is electricity. It could have been "all up with" Franklin during that experiment too. Other scientists who repeated the experiment were killed.

Charles Augustin Coulomb made careful studies of the forces exerted by both static electricity and magnetism in the 1780s. As early as 1733, Du Fay had discovered that there are two types of charge and that like charges repel while unlike charges attract. Coulomb showed that both magnets and electric charges obey the same rule, an inverse-square law. This implied a connection between electricity and magnetism. In 1807 Hans Christian Oersted announced that he would search for that connection.

Somewhat before this, there had been a major development in electricity that would facilitate Oersted's search. In 1771, while studying the reactions of muscle to electricity, Luigi Galvani accidentally discovered that the muscles of dead organisms twitch when placed in contact with brass and iron at the same time (published in 1791). Although Galvani thought the muscles were the sources of an electric charge, when Alessandro Volta learned of this phenomenon, Volta found that a simple chemical solution could be substituted for the muscles. With this knowledge, he cleverly constructed the first electric battery at the end of the 18th century. The battery was the first source of current electricity, electricity that moves steadily through a conductor as opposed to being quickly released from a Leiden jar.

The history of science is replete with stories of someone finding something by luck or accident. What is often overlooked in these tales is that the scientist in question had already been looking for something like the phenomenon he or she "accidentally" discovered. If Galvani had not been studying electric actions on muscle, he would not have been prepared to notice the reaction

of the muscle with the metals. Similarly, Oersted discovered the connection he sought by accident while he was performing a classroom demonstration. He placed a compass over a wire carrying a current. As he did, the needle suddenly moved to become perpendicular to the current. Electricity and magnetism really are connected.

As soon as Oersted's discovery became known in 1820, there was a burst of creative activity. In 1820 alone, André-Marie Ampère and Dominique François Arago discovered that wires carrying currents attract or repel each other and that an electric current in a wire will attract iron, just as a magnet does. In 1821 the thermoelectric effect was discovered by Thomas Seebeck. Two years later, William Sturgeon built the first electromagnet.

A notable series of investigations of the relationship between electricity and magnetism was conducted almost in parallel in England by Michael Faraday and in America by Joseph Henry. Both Faraday and Henry discovered the principle of the dynamo in 1830–31, for example. Although they independently discovered many of the same connections and devices, Faraday's work was to have the greater theoretical impact while Henry's had more immediate practical application.

Faraday had observed how iron filings form patterns of lines under the influence of a magnet. He concluded that space is filled with these invisible lines, forming what we now call a field. He used his idea to explain in 1845 why some substances are diamagnetic (developing a magnetic field opposite to the one surrounding them) and others paramagnetic (developing a magnetic field parallel to the one surrounding them). When Faraday discovered that a magnetic field can affect the polarization of light, he proposed in 1845 that light may be waves in the lines of force of electromagnetism.

There were other clues to a relationship between light and electromagnetism. In 1857, for example, Gustav Robert Kirchhoff calculated the relationship between the forces of static electricity and magnetism, finding that the speed of light in a vacuum is a constant in his formula. In 1864 James Clerk Maxwell followed up Faraday's ideas with mathematical formulas that described light as waves of electromagnetism and that implied other forms of electromagnetic waves. Maxwell's work was experimentally verified in 1888 when Heinrich Hertz, following a suggestion from George Francis Fitzgerald, discovered radio waves by directly applying Maxwell's formulas.

In America, Henry developed the first practical electric motor and powerful electromagnets in 1831. In the 1830s he also developed the electrical relay that made the first practical telegraph possible. Samuel Finley Breese Morse, usually given credit for the telegraph, worked directly with Henry and incorporated his ideas into the new device.

In 1879 Edison and Joseph Swan independently invented practical lights that use electricity. With this invention, electricity moved into the home, where the many discoveries of the 19th century soon found application.

André-Marie Ampère discovers that electric currents exert forces on each other; parallel wires attract or repel each other depending on whether currents are flowing in the same or in opposite directions. He also formulates another of the basic laws of electromagnetism, the right-hand rule for the influence of an electric current on a magnet: If the thumb on the right hand points to how a current-carrying wire moves in a magnetic field while the index finger points in the direction of the magnetic field, the bent second figure will point in the direction of the current. See also 1824 PHY; 1827 ENER.

Dominique François Arago discovers the magnetic effect of electricity passing through a copper wire, demonstrating that iron is not necessary for magnetism.

I Tools

Johann Salomo Christoph Schweigger [b. Erlangen (Germany), April 8, 1779, d. Halle, Germany, September 6, 1857], upon learning of Oersted's discovery of electromagnetism, uses the effect to build the first galvanometer, a tool for measuring the intensity and direction of an electric current. See also 1786 TOOL; 1850 TOOL.

Hans Christian Oersted invents an instrument for measuring the amount of an electric current, now known as the ammeter.

John Frederic Daniell [b. London, March 12, 1790, d. London, March 13, 1845] invents a dewpoint hygrometer. See also 1783 TOOL.

→ Transportation

John Birkinshaw of Durham builds rails for vehicles from wrought iron. See also 1785 TRAN.

1821

★ Astronomy

Alexis Bouvard [b. Contamines, France, June 27, 1767, d. Paris, June 7, 1843] uses various observations of Uranus made both before and after William Herschel's 1781 discovery of the planet to plot its orbit. He finds that earlier positions do not agree with later ones, an observation that will lead to the discovery of Neptune. See also 1808 AST; 1828 AST.

Joseph Fraunhofer locates and counts 574 dark lines in the solar spectrum. See also 1815 AST; 1823 AST.

Heinrich Christian Schumacher [b. Bramsted (Germany), September 3, 1780, d. 1832] founds the *Astronomische Nachrichten*, the oldest astronomical journal still published. See also 1826 MATH.

↗ Biology

Swedish botanist Elias Magnus Fries [b. August 15, 1794, d. Uppsala, Sweden, February 8, 1868] publishes the first of his three-volume *Systemia mycologicum*, which becomes a standard work on fungi.

● Earth science

Geologist Ignatz Venetz [b. Visperterminen, Switzerland, March 21, 1788, d. Saxon-les-Bains, Valais, Switzerland, April 20, 1857] is the first to propose that glaciers once covered much of Europe. See also 1779 EAR.

Mary Anning repeats her discovery of the first ichthyosaur by discovering the first known fossil of a plesiosaur; she is now 20 years old. See also 1811 EAR; 1822 EAR.

↗ Energy

Michael Faraday reports his discovery of electromagnetic rotation in the paper "On Some New Electro-Magnetical Motions, and on the Theory of Magnetism," essentially an application of the electromagnetic effect published in 1820 by Oersted. Technically, Faraday creates the first two motors powered by electricity in these experiments, although the rotating needle is not a motor in the normal sense and could not be used to power anything. See also 1819 PHY.

Σ Mathematics

Augustin Cauchy's *Cours d'analyse de l'Ecole Polytechnique* ("analysis course for the Ecole Polytechnique") is the first of three textbooks that puts elementary calculus into substantially the form that it is taught today, although it does not contain the modern definition of a limit. See also 1822 MATH.



Augustin-Louis Cauchy

[b. Paris, France, August 21, 1759, d. Sceaux, Seine, France, May 23, 1857]

Cauchy was the first to try to make mathematics rigorous, developing definitions and rules where intuition had reigned. Among these were definitions of the integral and rules for when sequences or series converge. His textbooks spread his ideas widely. He contributed to the study of complex functions and was the first to use groups.



Michael Faraday

[b. Newington, England, September 22, 1791, d. Hampton Court, England, August 25, 1867]

Although Faraday's work with electricity is better known, he began his scientific career as a chemist, synthesizing chloro-carbons and, in 1825, discovering benzene, the chemical that led to understanding all the aromatics. His principal studies of electricity began in 1830. Faraday then developed electric motors and generators and found the basic laws of electrolysis and induction. Faraday is renowned as an experimentalist, but his concept of a field based on lines of force has become one of the main underpinnings of theoretical physics.

♥ Medicine & health

Charles Bell gives the first description of the facial paralysis named for him (Bell's palsy).

⊗ Physics

Thomas Johann Seebeck discovers thermoelectricity, the conversion of heat into electricity that occurs at a junction of certain metals. Two different metals joined at two different places that are kept at different temperatures pro-

duce an electric current. This phenomenon will later be known as the Seebeck effect. *See also* 1834 PHY.

I Tools

Thomas Blanchard [b. Massachusetts, 1788, d. 1864] builds a machine used to carve wooden gunstocks for the Springfield, Massachusetts, Armory. It is based on a rotary cutter guided by a mechanical linkage that follows the movement of a tracing wheel over a given gunstock pattern. *See also* 1818 TOOL.

→ Transportation

British engineer Henry Robinson Palmer [b. Hackney, England, 1795, d. 1844] patents a monorail system and builds an elevated monorail line linking the Royal Dock Victualling Yard and the river Thames.

1822

▲ Archaeology

English antiquarian William Bullock explores Teotihuacán and other ruins in the Valley of Mexico. He brings back relics and casts of Aztec works of art and monuments for display in England. The exhibit, in 1824, creates new interest among the English in New World civilizations. *See also* 1839 ARCH.

Jean-François Champollion [b. Figeaci, France, December 23, 1790, d. Paris, March 4, 1832] translates the hieroglyphic panel of the Rosetta Stone, the first translation of Egyptian hieroglyphics. *See also* 1799 ARCH.

★ Astronomy

At the behest of Pope Pius VII, the Catholic Church recognizes that the solar system of Copernicus is a physical fact and not

just a working hypothesis. *See also* 1616 AST; 1835 AST.

On May 24 Christian Carl Ludwig Rümker [b. Stargard (Germany), May 18, 1788, d. Lisbon, Portugal, December 21, 1862] observes the first calculated return of a short-period comet. The observation of Encke's comet takes place at the newly created Paramatta Observatory in New South Wales, Australia. *See also* 1758 AST.

□ Chemistry

Jöns Jakob Berzelius begins publication of his *Jahres-Bericht*, an annual review reporting his own research and that of other chemists.

□ Communication

Sampson Mordan and John Isaac Hawkins start the mechanized manufacture of pencils in the United States. They also improve Joseph Bramah's pens, made from parts of goose quills, by replacing the quill with horn or tortoise-shell points (nibs) tipped with jewels or gold. *See also* 1809 COMM; 1830 COMM.

John Mitchell is thought to have developed the first machine-made steel pens about this time. *See also* 1809 COMM; 1830 COMM.

Joseph Niépce and Claude Niépce, using silver chloride, produce the first fixed positive image that could be called a photograph. *See also* 1816 COMM; 1839 COMM.

According to some sources, Christian Friedrich Buschmann [b. 1775, d. 1832] invents the accordion in Berlin, although others claim it is a slightly later Viennese invention. *See also* 1829 COMM.

□ Computers

Charles Babbage develops the Difference Engine, a machine for calculating values of logarithms and trigonometric functions. It does not work well owing to an inability to make parts that live up to Babbage's design. Soon he will abandon the Difference Engine for a general-purpose computer. *See also* 1805 TOOL; 1832 COMP.

■ Construction

Guillaume Henry Dufour [b. Constance, Switzerland, September 15, 1787, d. July 14, 1875] and Marc Seguin [b. Annonay, France, April 20, 1786, d. Annonay, February 24, 1875] start construction of the first large suspension bridge in Europe. The bridge, erected in Geneva, consists of two sections of 40 m (131 ft) each. *See also* 1809 CONS; 1823 CONS.

□ Earth science

Mary Ann Mantell or her husband, physician and amateur geologist Gideon Algernon Mantell [b. Lewes, England, February 3, 1790, d. London, November 10, 1852] discovers the first fossil that will be recognized as a dinosaur, which Gideon names *iguanodon* after seeing similarities to a giant iguana. Although their published tale has Mary Ann as the discoverer, research suggests that it is possible that Gideon actually found the first teeth and bones. *See also* 1821 EAR; 1842 EAR.

Grundriss der Mineralogie ("outline of mineralogy") by Friedrich Mohs [b. Gernrode, Anhalt-Bernburg (Germany), January 29, 1773, d. Agardo (Italy), September 29, 1839] introduces the Mohs system of classifying minerals and the Mohs scale of mineral hardness.

In France, Jean-Baptiste Julien d'Omalius d'Halloy [b. Lièges, Belgium, February 16, 1783, d. Brussels, January 15, 1875] identifies the Cretaceous period in Earth's history (to describe fossil-bearing chalk beds in northern France). In England, William Daniel Conybeare [b. London, June 7, 1787, d. Portsmouth, England, August 12, 1857] and William Phillips [b. 1775, d. 1828] identify the Carboniferous period in Earth's history, named after the coal seams found in rock strata from this period. *See also* 1799 EAR; 1833 EAR.

■ Food & agriculture

Anselme Payen [b. Paris, January 6, 1795, d. Paris, May 12, 1871] discovers that charcoal can be used to remove impurities from sugar. *See also* 1802 FOOD.

◊ Materials

Augustin Cauchy presents his theory of stress and strain to the French Academy of Sciences. It provides the first careful definition of stress as the load per unit area of the cross section of a material. *See also* 1807 MATR; 1826 MATR.

Σ Mathematics

Scottish essayist and historian Thomas Carlyle [b. Dumfries-shire, Scotland, December 4, 1795, d. London, February 5, 1881] makes the second translation of Adrien-Marie Legendre's *Éléments de géométrie* ("elements of geometry") into English. Carlyle's version becomes the most popular geometry textbook in the United States during the 19th century. *See also* 1821 MATH.

Traité des propriétés projectives des figures ("treatise on the

projective properties of figures") by Jean-Victor Poncelet [b. Metz, France, July 1, 1788, d. Paris, December 23, 1867] is the first systematic development of projective geometry. *See also* 1639 MATH; 1826 MATH.

Karl Wilhelm Feuerbach [b. Jena (Germany), May 30, 1800, d. Erlangen, Germany, March 12, 1834] publishes what is now known as Feuerbach's theorem (discovered the year before by Jean-Victor Poncelet and Charles Julien Brianchon [b. Sèvres, France, December 19, 1783, d. Versailles, France, April 29, 1864]). It states that the nine-point circle of a triangle (that is, the circle through the midpoints of the three sides of a triangle, which also passes through six other easily characterized points) is tangent internally to the inscribed circle of the triangle and externally to the three excircles, which are tangent to the side and to the extensions of the other two sides.

Jean-Baptiste Joseph Fourier's *La théorie analytique de la chaleur* ("analytic theory of heat") proves that any continuous function can be found as the sum of an infinite number of sine and cosine curves, the foundation of what is now known as Fourier analysis. This is an important result since both the sine and cosine functions are easy to use in calculus, so intractable functions can be rewritten as a Fourier series for differentiation or integration. *See also* 1817 MATH; 1831 MATH.

♥ Medicine & health

William Beaumont [b. Lebanon, Connecticut, November 21, 1785, d. St. Louis, Missouri, April 25,

1853] starts his experimental study of digestion in the stomach that remains exposed in a wounded man. *See also* 1690 MED; 1838 MED.

The first successful hysterectomy is performed. *See also* 1736 MED; 1825 MED.

Jean Pierre Marie Flourens [b. France, 1794, d. 1867] shows that vision depends on the cerebral cortex and that the cerebellum controls coordination. *See also* 1847 COMM.

Building on work by Charles Bell, François Magendie proves that the ventral (front) root of each spinal nerve has a motor function and the dorsal (back) root has a sensory function. *See also* 1811 MED; 1830 MED.

I Tools

Augustin Fresnel invents the Fresnel lens, a lens used in lighthouses. For a time, lighthouses that use reflectors are said to use the English system, while those with lenses use the French system, but by the end of the 19th century most lighthouses use a combination of lenses and reflectors. *See also* 1763 TOOL.

1823

★ Astronomy

Joseph von Fraunhofer observes the spectra of stars. He detects dark lines in them that are different from those observed in his study of dark lines in the spectrum of the Sun. When the significance of these lines is recognized more than a quarter of century later, it is apparent that the difference in position means that stars have a different chemical composition from the Sun. *See also* 1821 AST; 1858 AST.

□ Chemistry

Michael Faraday's *On Fluid Chlorine* describes the liquefaction of chlorine by cooling and reports properties of the fluid.

□ Communication

Johannes Purkinje is the first to classify various types of fingerprints and to recognize that fingerprints can be utilized as a means of identification. *See also* 1680 MED; 1860 COMM.

Franz Joseph Gall begins his definitive statement on phrenology, the six-volume *Sur les fonctions du cerveau* ("on the functions of the brain"), which will not be completed until 1825. *See also* 1810 MED.

■ Construction

The British Museum, designed by Robert Smirke [b. London, 1781, d. Cheltenham, England, April 18, 1867] is built in the Greek revival fashion, resembling a temple with Ionic columns. *See also* 1819 CONS.

The Grand Pont crossing the Saône River at Fribourg, Switzerland, 273 m (896 ft) long, is the most successful large suspension bridge up to this time. It remains in service until 1923, unlike many other suspension bridges of the early 19th century, most of which collapse as soon as they encounter a violent wind-storm. *See also* 1822 CONS; 1825 CONS.

■ Earth science

Denison Olmsted [b. 1791, d. 1859] conducts the first American state geological survey, in North Carolina. *See also* 1811 EAR.



Johannes Evangelista Purkinje

[b. Libochovice, Bohemia (Czech Republic), December 17, 1787, d. Prague, July 28, 1869]

In addition to expanding our knowledge of the structure and function of the eye, Purkinje was a pioneer in the study of cells, particularly after acquiring a compound microscope in 1832. His discoveries include the nucleus in birds' eggs, sweat glands in the skin, large flask-shaped nerve cells with numerous dendrites in the cerebellum (now called Purkinje cells), and muscle fibers in the heart that conduct stimuli from the pacemaker (Purkinje fibers). He was the first to realize that fingerprints can be used for identification, the first to describe the movement of cilia, and the first to use a microtome (an instrument used to slice tissue into thin sections for microscopic examination).

Reliquiae Diluvianae: Observations on the Organic Remains Contained in Caves, Fissures, and Diluvial Gravel, and on Other Geological Phenomena, Attesting the Action of a Universal Deluge by William Buckland [b. Axminster, England, March 12, 1784, d. August 15, 1856] sets the time of Noah's Flood at about five to six thousand years before the present. Buckland reports that he has found the fossils of many creatures at Kirkdale Cave in Yorkshire, including elephants, hippopotamuses, and tigers. He argues that these animals were present in England before Noah's Flood. *See also* 1824 EAR.

❖ Materials

Charles Macintosh [b. Glasgow, Scotland, December 29, 1766, d. July 25, 1843] dissolves rubber in low-boiling naphtha and invents the waterproof fabric that bears his name, although usually spelled mackintosh. Raincoats made from this fabric or other waterproof fabrics are also sometimes called mackintoshes. *See also* 1839 MATR.

Σ Mathematics

Niels Henrik Abel [b. Finnøy Island, near Stavanger, Norway, August 5, 1802, d. Froland, Norway, April 6, 1829] is the first consciously to propose and solve an integral equation (an equation that contains an unknown under the integration sign), although Pierre-Simon Laplace and Joseph Fourier had without recognizing it solved problems as early as 1782 that involved integral equations.

Abel begins with the problem of finding the position of a particle sliding down an unknown curve from rest toward its lowest point when only the time for reaching that point is known. Abel also generalizes the problem and develops two methods for solving integral equations. *See also* 1782 MATH.

1824

★ Astronomy

Joseph von Fraunhofer builds the first telescope to be mounted equatorially with a clock drive, the Dorpat refractor — named for the observatory of Dorpat (Tartu, Estonia), where it is installed. Equatorial mounts and clock drives had both been introduced by the Chinese, but they did not have telescopes with lenses or mirrors. *See also* 1270 AST.

Marie-Charles-Théodore Damoiseau [b. April 9, 1768, d. August 8, 1846] creates the *Tables lunaires* (“lunar tables”) published by the Bureau des Longitudes. *See also* 1834 AST.

❧ Chemistry

Friedrich Wöhler and Justus von Liebig [b. Darmstadt (Germany), May 12, 1803, d. Munich, Bavaria, April 18, 1873] each find the formula of different chemical compounds. Joseph Louis Gay-Lussac notes that the two formulas are the same. It is the first discovery of chemical isomers, chemicals that differ only in molecular structure. *See also* 1830 CHEM.

Jöns Jakob Berzelius discovers the element silicon (Si). Berzelius also isolates zirconium (Zr), which had been discovered in the form of zirconium oxide by Martin Klaproth. Klaproth is usually given credit for his first recognition of zirconium as an element. *See also* 1789 CHEM.

⌚ Communication

Henry Kater [b. Bristol, England, 1777, d. London, 1835] uses a pendulum to determine an exact ratio for the yard measure, which he then inscribes on a metal bar. This is the yard by government decree in England, defined on the basis of

the length of a pendulum with a period of one second placed in Greenwich. The standard bar, along with other measures, is lost when Parliament burns in 1834, and has to be reconstructed. *See also* 1843 COMM.

The first school of science and engineering opens in the United States. Later it will be called Rensselaer (New York) Polytechnic Institute.

Louis Braille [b. Coupvray, France, January 4, 1809, d. January 6, 1852] introduces a method of writing the alphabet using a pattern of raised dots made with a stylus. This alphabet comes to be used by blind persons all over the world, with many books published using the system in addition to personal communications and note taking. *See also* 1784 COMM.

Peter Mark Roget [b. 1779, d. 1869], better known as the author of the famous *Thesaurus*, writes about the persistence of vision and demonstrates that this phenomenon permits a quickly displayed series of still images to seem to be moving. This in turn leads to many devices to show pictures that appear to move. *See also* 1829 CHEM.

🌐 Earth science

William Buckland publishes

Notice on the Megalosaurus or Great Fossil Lizard of Stonesfield, which contains the first printed account of any recognized dinosaur. It is Buckland, now president of the Geological Society, who names the fossil *Megalosaurus* (“great lizard”). *See also* 1677 EAR; 1841 EAR.

☛ Energy

Réflexions sur la puissance motrice du feu (“reflections on the motive power of fire”) by (Nicolas Léonard) Sadi Carnot [b. Paris, June 1, 1796, d. Paris, August 24, 1832] shows that work is done as heat passes from a high temperature to a low temperature and suggests internal combustion engines. It also hints at the second law of thermodynamics (heat cannot pass from a low temperature to a higher one without help). *See also* 1782 ENER; 1850 ENER.

❖ Materials

English mason and building contractor Joseph Aspdin [b. 1778, d. March 20, 1855] patents Portland cement. It is obtained by a very high calcination temperature. The end product, after mixing with water and setting, looks like stone obtained from the Island of Portland, hence its name. *See also* 1759 CONS.



Friedrich Wöhler

[b. Eschersheim (Germany), July 31, 1800, d. Göttingen, Germany, September 23, 1882]

Wöhler was an outstanding chemist in many ways. With Justus von Liebig he discovered that the same radical can appear in several related compounds. Wöhler was also the first to isolate aluminum, beryllium, boron, silicon, and titanium. Wöhler's fame is based on his synthesis of urea, understood in 1828 as the first creation of an organic compound from an inorganic one. At the time, most chemists believed that chemicals produced by living creatures, such as urea, were essentially different from chemicals derived from minerals. Since then science historians have found an earlier example of synthesis of an organic compound and have termed the precursor Wöhler used only partly organic.

The nature of heat

In Aristotle's physics, heat is one of the active qualities of a body. Hotness, as well as dryness, and their opposites, coldness and moistness, were the qualities that defined an element.

Later, heat and temperature came to be viewed as lesser fundamental properties of matter, but opinions about the nature of heat varied sharply. Francis Bacon defined heat as local motion, and René Descartes and Robert Hooke described heat as the ceaseless motion of particles. Others, such as the Dutch physician Hermann Boerhaave, described heat as a subtle fluid, later called caloric, that could pass from one object to another.

During the beginning of the 19th century, the theory that heat was a form of motion won over the liquid, or caloric, theory. Even earlier, at the end of the 18th century, Count Rumford (Benjamin Thompson) had observed the large amount of heat produced during the boring of cannons and reached the conclusion that heat was added to the cannon by motion.

The German physician Julius Robert Mayer was one of the first to relate heat directly to mechanical work, writing of his discovery in 1842. That heat and mechanical work are both forms of energy was a very important discovery. It became the basis of a new science that gained quickly in importance during the 19th century: thermodynamics.

Sadi Carnot, intrigued by why British steam engines were more efficient than French ones, started investigating the physical processes that take place in a steam engine. Although he believed that heat was an indestructible fluid, he was the first to apply physics to a technical problem. He published the results in 1824 as *Réflexions sur la puissance motrice du feu* ("reflections on the motive power of fire"). However, this paper remained little known for ten years, until Emile Clapeyron discussed it in the *Journal de l'Ecole Polytechnique*.

Carnot had found that the efficiency of a machine depends on the difference in temperature between the heat source that supplies the work (hot reservoir) to the machine and the temperature reservoir into which the machine discharges excess heat (cold reservoir). The mechanical equivalent of heat is the amount of heat that can produce a given amount of motion. Although Carnot had found an approximate value for the mechanical equivalent of heat, he died too early, at the age of 36, to publish this result.

Contrary to Carnot, James Prescott Joule believed that heat was a quantity that was destroyed in a machine to produce mechanical work. In a series of famous experiments, he measured the increase of temperature of water stirred by a determined amount of mechanical work. As a result, Joule also determined the mechanical equivalent of heat, five years after the similar work of Julius Mayer. His work was more quickly recognized than Mayer's, however, since Joule was a physicist and Mayer a physician.

Claude Burdin [b. Lépin, Savoy (Italy) May 18, 1778, d. Clermont, France, November 12, 1873] coins the term "turbine" for a power source deriving motion from a flowing fluid. The name is derived from the Latin *turbo*, a spinning object. *See also* 1827 ENER.

Σ Mathematics

Niels Henrik Abel proves that it is impossible to find roots for an equation of the fifth degree or greater using radicals (an earlier overlooked proof in 1799 by Paolo Ruffini was unknown to Abel and is considered to be less convincing than Abel's proof). *See also* 1799 MATH; 1830 MATH.

In a letter to Franz Taurinus, Gauss reveals that he has discovered and accepted non-Euclidean geometry but wishes to keep it secret. *See also* 1826 MATH.

♥ Medicine & health

English physician Henry Hill Hickman [b. 1800, d. April 5, 1830] uses carbon dioxide on an animal as a general anesthetic. *See also* 1800 MED; 1842 MED.

⌘ Physics

William Sturgeon [b. Whittington, England, May 22, 1783, d. Prestwick, England, December 4, 1850] makes the first electromagnet. Recognizing from Faraday's work that wrapping a conducting wire around a core sets up an electric field inside the core, he wraps varnished wires around an iron core and discovers that the iron becomes a magnet when current flows through the wires. (The varnish is to insulate the current-carrying wires from the iron.) In 1825 he will be able to demonstrate an electromagnet that can lift

as much as 4 kg (9 lb). *See also* 1820 PHY; 1829 PHY.

I Tools

Joseph Louis Gay-Lussac invents the alcoholometer, a device for measuring the proof of liquors that is still in use today. *See also* 1768 TOOL.

1825

★ Astronomy

On October 11 (Samuel) Heinrich Schwabe [b. Dessau (Germany), October 25, 1789, d. Dessau, April 11, 1875] starts observing the Sun as a part of his search for a planet between Mercury and the Sun. Starting in 1826, he makes frequent drawings of spots on the Sun (which might be the nonexistent planet). These records will eventually lead him to the dis-

covery of the sunspot cycle. *See also* 1611 AST; 1843 AST.

□ Chemistry

Michel-Eugène Chevreul [b. Angers, France, August 31, 1786, d. Paris, April 9, 1889] and Joseph Louis Gay-Lussac patent a method of making candles from fatty acids. These candles, made from stearin, a colorless, odorless fat produced from glycogen and stearic acid, are a great improvement on tallow candles commonly in use. The two chemists are hailed as benefactors of humankind. *See also* 1850 MATR.

German student Carl Löwig discovers bromine (Br), but the new element is not announced until rediscovery by Antoine Jérôme Balard [b. Montpellier, Hérault, France, September 30, 1802, d. Paris, March 30, 1876] in 1826.

Jöns Jakob Berzelius isolates the chemical element titanium (Ti). The chemical element had been discovered as an oxide in 1795 by Martin Klaproth.

Hans Christian Oersted discovers aluminum (Al) by using electric currents and chlorine to produce anhydrous aluminum chloride from alumina; he then dissolves this compound in mercury and distills metallic aluminum from it. *See also* 1828 MATR.

Michael Faraday isolates benzene by fractionally distilling whale oil. *See also* 1825 FOOD; 1865 CHEM.

Communication

John Ayrton [b. Paris, 1785, d. 1856] develops the Thaumatrope, a persistence of vision device that produces moving images and becomes a popular toy. *See also* 1832 COMM.

Construction

A suspension bridge over Menai Straits in Wales, built by Thomas Telford [b. Scotland, August 9, 1757, d. London, September 2, 1834], with a single span of 176 m (579 ft), inaugurates the age of modern bridge construction. *See also* 1823 CONS; 1831 CONS.

Earth science

The French *Corps Royal des Mines* starts fieldwork on the *Carte géologique de la France* ("geological map of France"), which is to become the world's first national geological survey. *See also* 1811 EAR.

Georges Cuvier announces his catastrophe theory in *Discours sur les révolutions de la surface du globe, et sur les changemens qu'elles ont produits dans le règne animal* ("discourse on the revolutionary upheavals on the surface of the globe

and on the changes which they have produced in the animal kingdom"), the introductory volume to *Recherches sur les ossemens fossiles des quadrupèdes*. The basis of the theory is that great catastrophes have caused the extinction of large groups of animal species and altered Earth's geology as well. *See also* 1812 EAR.

Energy

Scottish engineer Thomas Drummond [b. Edinburgh, October 10, 1797, d. April 15, 1840] and Goldsworth Gurney [b. England, 1798] invent limelight, an intense beam of light focused by a parabolic mirror and produced by burning lime in an alcohol flame enriched by additional oxygen.

Food & agriculture

Michael Faraday prepares benzene hexachloride, which

in the 20th century will be recognized as the first of a family of insecticides that appear to be almost harmless to most vertebrates. *See also* 1800 FOOD; 1874 FOOD.

Mathematics

Elliptic functions, those with double periodicity, are discovered by Niels Abel (published in 1827). The period of a function is the length before the function repeats the same value. The most familiar are trigonometric functions, such as the sine, with a single period of 360° (2π). Elliptic functions are complex functions with two periods. The same kind of functions are independently discovered by Carl Jacobi in 1829 and probably also by Gauss in 1808, although never published by Gauss. *See also* 1722 MATH; 1854 MATH.

Understanding fossils

Little progress in understanding fossils took place during the 18th century — although Comte de Buffon recognized that different groups of fossilized organisms appeared at different times in the past. Thomas Jefferson, who collected fossils, firmly believed that they were the remains of living organisms, but he thought that any organisms that he did not recognize were alive somewhere on Earth. He did not believe that the Creator would permit extinction.

In the 19th century geologists began to understand that Earth had lasted long enough for many forms of life to have arisen and become extinct. Georges Cuvier, in 1811, showed that fossil bones previously ascribed to human victims of Noah's Flood were actually the remains of a giant salamander. Cuvier also recognized various other fossils, including marine reptiles and flying reptiles. In 1825 he put forth three hypotheses about the origins of such fossils, each of which had merit, although he considered them to be mutually exclusive.

The first was the same as that of Thomas Jefferson: These creatures are still alive in some unexplored part of Earth; As it hap-

pens, every so often such a "living fossil" is found. An example is the coelacanth, a fossil fish believed to have been extinct for 65,000,000 years when it was found alive in 1938. The second hypothesis was that organisms change shape over the course of time. This is a version of the theory of evolution. Finally, he suggested that some organisms may be extinct, which is the actual case for most organisms found as fossils. Cuvier rejected his first two hypotheses in favor of the third. He believed that from time to time great catastrophes caused all life to become extinct. Following each catastrophe, he alleged, the Creator put a new set of organisms on Earth.

At the same time as Cuvier's book on the subject was published, Gideon Mantell recognized some fossil teeth as belonging to a giant reptile. Other fossils with similar characteristics were found. In 1842 Richard Owen coined the word *dinosaur* to describe these common reptiles. In 1854 Owen prepared an exhibition of dinosaurs for display at the Crystal Palace. Dinosaurs excited the public enormously.

Darwin's theory of evolution, which became known a few years later, finally gave the philosophical basis for fossils that we still use today.



TELFORD'S BRIDGE OVER MENAI STRAITS The first major suspension bridge took six years to build and was a record 176 m (579 feet) in length. The roadway, suspended from a chain of wrought-iron links, had to be 30 m (100 ft) above sea level to permit tall sailing ships to pass under it. The bridge still stands near Anglesey, Wales.

Peter Gustav Lejeune Dirichlet [b. Düren (Germany), February 13, 1805, d. Göttingen, Germany, May 5, 1859] presents a flawed proof that Fermat's "last theorem" is true for $n = 5$. The flaws are soon corrected by Adrien-Marie Legendre. Previously the theorem had been shown true for $n = 3$ and $n = 4$ (the case $n = 4$ having been used by Fermat to illustrate his method of infinite descent). See also 1770 MATH; 1839 MATH.

❖ Physics

André-Marie Ampère develops a theory relating magnetism to electricity. He proposes that magnetism is caused by the movement of very small electrical charges in bodies. Although something like this is now thought to be true, his contemporaries were not impressed. See also 1820 PHY.

I Tools

Henry Burden [b. 1791, d. 1871] of Troy, New York, begins to manufacture railroad spikes by machinery, rather than making them by hand. See also 1835 TOOL.

→ Transportation

George Stephenson's locomotive Active (later renamed Locomotion No. 1) makes its initial trip on the Stockton & Darlington Railway in Durham County, England, on September 27, becoming the first steam locomotive to carry regularly both passengers and freight. See also 1814 TRAN; 1830 TRAN.

George Cayley invents the use of full treads instead of wheels for vehicles. See also 1770 TRAN; 1908 FOOD.

The 586-km (364-mi) Erie Canal from Albany, New York, to Buffalo, New York, is officially opened on October 26. At 10:00 a.m. in Buffalo a cannon is fired, followed by responses down the length of the canal and the Hudson to New York City, a sequence of firings that carries the message of the opening to New York City in a matter of 81 minutes. Construction on the canal had started in 1817, and the finished canal is the first in the United States to have a major impact on trade. It becomes the foundation of the New York State Barge Canal System,

a complex of 4 canals, 56 locks, and associated waterways. See also 1803 TRAN; 1829 TRAN.

1826

★ Astronomy

Heinrich Olbers formulates his version of the paradox named after him: If stars are distributed evenly through infinite space, why is the night sky dark? In the 20th century the understanding from cosmology that the universe has a limited age will bring a solution to this paradox. See also 1744 AST; 1845 AST.

Wilhelm von Biela [b. Rossla, Austria, March 19, 1782, d. Venice (Italy), February 18, 1856] calculates the orbit of a short-period comet that by 1846 has split in two and by 1866 has disappeared altogether, showing for the first time that some comets have short lifetimes. See also 1846 AST.

❖ Biology

Physiologist Ernst Heinrich Weber [b. Wittenberg (Germany), June 24, 1795, d. Leipzig, Saxony, January 26, 1878] starts his experiments

with the two-point threshold of sensation: When two points of simulation on the skin are close, they are perceived as a single-point sensation.

❖ Chemistry

German chemist Otto Unverdorben [b. October 13, 1806, d. 1873] discovers aniline, a compound used in the manufacture of dyes, plastics, and pharmaceuticals, by distilling indigo. See also 1845 MATR.

French chemist and biologist (René Joachim) Henri Dutrochet [b. November 14, 1776, d. February 4, 1847] studies osmosis and discovers the laws governing this process, which carries fluids through semi-permeable membranes. See also 1891 BIO.

Antoine-Jérôme Balard, studying seaweed, discovers the chemical element bromine (Br). See also 1811 CHEM.

❖ Communication

Joseph Niépce uses sunlight to harden asphalt, reproducing a photograph on the asphalt that can then be used as a printing plate. See also 1823 COMM; 1855 COMM.

█ Computers

Charles Babbage publishes *On a Method of Expressing by Signs the Action of Machinery*, in which he develops a way of describing machines in a mathematical code that is applicable to all machines. *See also* 1822 COMP; 1832 COMP.

⊕ Earth science

German geologist Christian Leopold von Buch [b. Stolpe, Prussia (Germany), April 25, 1774, d. Berlin, March 4, 1853] makes the first geologic map of Germany. *See also* 1825 EAR.

◊ Materials

Claude-Louis-Marie-Henri Navier [b. Dijon, France, February 10, 1785, d. Paris, August 21, 1836] puts the concept of Young's modulus into modern mathematical form, as stress over strain. *See also* 1807 MATR; 1829 MATR.

Σ Mathematics

August Leopold Crelle [b. Eichwerder (Germany), March 11, 1780, d. Berlin, October 6, 1855] launches *Journal für die reine und angewandte Mathematik* ("journal of pure and applied mathematics"), commonly known as *Crelle's Journal*, the first periodical devoted exclusively to research in pure mathematics (the "applied" in the title was regularly ignored). *See also* 1821 AST; 1836 MATH.

Jean-Victor Poncelet and Joseph Diaz Gergonne discover the principle of duality; that is, in theorems of projective geometry, one can exchange the words *point* and *line* to obtain a new, correct theorem. *See also* 1822 MATH; 1829 MATH.

On February 23 Nikolai Ivanovich Lobachevski [b. near Nizhni Novgorod, Russia, December 2, 1793, d. Kazan, Russia, February 24, 1856] delivers a paper to the mathematics and physics staff at Kazan University that is believed to have contained an outline of his ideas about non-Euclidean geometry. *See also* 1824 MATH; 1829 MATH.

♥ Medicine & health

René Laënnec writes *De l'auscultation médiate et des maladies des poumons et du cœur* ("on using sound to diagnose maladies of lungs and heart"), presenting an extension of his work on the use of the stethoscope. *See also* 1819 MED.

Pierre Bretonneau describes the symptoms of and names diphtheria.

☒ Tools

Alan Wood's water-powered rolling mill near Wilmington, Delaware, the Delaware Iron Works, begins to make shovels and spades in large quantities by machinery. The Collins Company is formed in Connecticut to mass produce axes using machinery to make the parts.

→ Transportation

Samuel Morey [b. Hebron, Connecticut, October 23, 1762, d. Fairlee, Vermont, April 17, 1843] starts building the *Aunt Sally*, believed to be the first boat to be powered by an internal combustion engine. Sometime between 1832 and 1843 the *Aunt Sally* sinks or is sunk by the inventor. *See also* 1797 TRAN; 1991 TRAN.

Marc Isambard Brunel designs floating landing stages for the port of Liverpool.

1827

↗ Biology

French-American ornithologist John James Audubon [b. Les Cayes, Santo Domingo (Haiti), April 26, 1785, d. New York, New York, January 27, 1851] starts publication of *Birds of America*, a collection of lifelike drawings that are published in Europe. *See also* 1797 BIO.

De ovi mammalium et hominis genesi ("on the origin of the mammalian and human ovum") by German-Russian embryologist Karl Ernst von Baer reports his discovery of

eggs in mammals and humans, and that mammals develop from eggs, disproving the theory that a completely formed mammal exists in miniature within the embryonic material. *See also* 1817 BIO; 1828 BIO.

↳ Communication

Jacques Babinet [b. Lusignan, France, March 5, 1794, d. Paris, October 21, 1872] suggests using the wavelength of light as a basis for standard measures, a suggestion adopted between 1960 and 1983, when the meter is based on the wavelength of light from the gas krypton. *See also* 1824 COMM; 1960 COMM.



AUDUBON'S GREAT HORNED OWL The lifelike illustrations in Audubon's *Birds of America* were achieved through extensive field studies instead of relying solely on stuffed birds as had been the practice of earlier artists. As a result of his attention to detail, Audubon is considered a great scientist as well as a great artist. He also prepared the illustrations and co-authored the text of *Viviparous Quadrupeds of North America*.



Karl Ernst von Baer

[b. Piep (Estonia), February 28, 1792, d. Tartu (Estonia), November 28, 1876]

Famed for his discovery of the mammalian egg cell, Baer also discovered the membranes around the embryo and described their function. He formulated basic principles of embryonic development. The purpose of early development of a zygote (fertilized egg) is to form layers of tissue, which then form all the various organs of the body. An embryo develops from simple to complex; general characteristics appear before special characteristics. In their early stages, young embryos of various species resemble one another, but as each species develops it moves progressively away from this resemblance.

Ecology & the environment

Jean-Baptiste Fourier suggests that human activities might have an effect on Earth's climate. See also 1967 ECOL.

Energy

Die galvanische Kette, mathematisch bearbeitet ("the galvanic circuit investigated mathematically") by Georg Simon Ohm [b. Erlangen (Germany), March 16, 1789, d. Munich, July 7, 1854] contains the first statement of what is eventually called Ohm's law — that the current of electricity is equal to the ratio of the voltage to the resistance. See also 1820 PHY; 1829 PHY.

John Walker [b. Stockton-on-Tees, England, 1771, d. May 1,

1859] invents the friction match, the first match that can be ignited by pulling it through sandpaper. Its tip is coated with antimony sulfide and potassium chlorate. See also 1830 ENER.

Benoit Fourneyron [b. Bornin St.-France, 1802, d. St. Etienne, France, July 8, 1867] builds the first enclosed water turbine of a modern design. It develops 4.5 kW (6 hp) of power. The first water wheels, some 2000 years earlier, were also turbines, but not nearly so efficient. See also 1791 ENER; 1831 ENER.

Jacob Perkins [b. Newburyport, Massachusetts, July 9, 1766, d. London, July 30, 1849] patents a steam engine with a piston that acts as the exhaust valve. This is a second version of the "uniflow" engine, as this type becomes known during the 20th century. See also 1885 ENER.

Mathematics

Gauss's *Untersuchungen zur Differentialgeometrie* introduces the subject of differential geometry, by means of which the small features of curves and surfaces are described using the techniques of analysis.

Der barycentrische Calcul ("barycentric calculus") by August Ferdinand Möbius [b. Schulpforte (Germany), November 17, 1790, d. Leipzig, Saxony, September 26, 1868] is probably the first work to use homogeneous coordinates (a method of locating a point that gives the same point for any multiple of the coordinates), although Karl Feuerbach, Julius Plücker, and Étienne Bobillier invent the same idea around the same time. See also 1803 MATH.

Medicine & health

Physician Richard Bright [b. Bristol, England, September 28, 1789, d. London, December 16, 1858] gives a description of the symptoms of Bright's disease, a kidney disorder.

Charles-Eduard-Ernest Delezenne [b. Lille, France, October 4, 1776, d. Lille, August 26, 1866] develops his technique of "just noticeable differences" to study hearing.

Physics

Botanist Robert Brown [b. Montrose, Scotland, December 21, 1773, d. London, June 10, 1858], using a microscope, discovers that tiny particles suspended in a liquid are constantly in motion. This "Brownian motion" nearly 100 years later will become the first concrete indication that molecules really exist. See also 1905 PHY.

Theory of Systems of Rays by William Rowan Hamilton [b. Dublin, Ireland, August 4, 1805, d. Dunsink, Ireland, September 2, 1865] is a unification of the study of optics through the principle of "varying action" and contains Hamilton's correct prediction of conical refraction.

André-Marie Ampère's *Mémoire sur la théorie mathématique des phénomènes électrodynamiques uniquement déduite de l'expérience* ("notes on the mathematical theory of electrodynamic phenomena deduced solely from experiment") contains the inverse square law for magnets. See also 1767 CHEM.

1828

Astronomy

The observed position of Ura-

nus differs so much from its calculated orbit that astronomers start looking for another planet that may disturb its orbit; this will lead to the discovery of Neptune nearly 20 years later. See also 1846 AST.

Biology

Karl Ernst von Baer's *Über Entwicklungsgeschichte der Tiere* ("the developmental history of animals") describes how fertilized egg cells develop into embryos and discusses his "germ layer theory," according to which eggs form four layers of tissue. See also 1827 BIO; 1845 BIO.

Chemistry

Friedrich Wöhler prepares an organic compound, urea from inorganic compounds, proving that the idea that organic compounds can only be produced by living organisms is wrong. See also 1799 CHEM; 1845 CHEM.

Friedrich Wöhler and Antoine-Alexandre Brutus Bussy prepare pure beryllium (Be).

Jöns Jakob Berzelius publishes a revised version of his table of atomic weights, with many elements having atomic weights close to presently accepted values. See also 1834 CHEM.

Communication

Francis Leiber [b. Germany, 1798, d. 1872] begins publication in Boston of the first edition of the *Encyclopédie Americana*, largely based on Brockhaus' *Conversations-Lexicon*. See also 1796 COMM.

The Institution of Civil Engineers is granted a royal charter in England. See also 1771 COMM; 1847 COMM.

Earth science

German physicist Paul Erman

[b. Berlin, February 29, 1764, d. Berlin, October 11, 1851] measures the magnetic field of the Earth. His measurements become the basis for Gauss's theory of Earth's magnetic field. *See also* 1766 EAR; 1849 EAR.

❖ Ecology & the environment

John Vaughan Thompson [b. Ireland, 1779, d. 1847] is the first to collect and describe plankton (the term *plankton*, however, will be introduced in 1887 by Viktor Hensen [b., Germany, 1835, d. 1924]).

❖ Materials

Friedrich Wöhler develops a new method to prepare aluminum in pure form; because of the complexities of the chemistry required, aluminum remains the most expensive metal on Earth at this time. Because of this, aluminum jewelry will sometimes be made during the 19th century. *See also* 1825 CHEM; 1886 MATR.

John Thorp [b. Rehoboth, Massachusetts, 1784, d. November 15, 1848] introduces ring spinning, a method for continuous spinning still in use today. *See also* 1793 TOOL.

♥ Medicine & health

Amalgam, a mercury alloy, is introduced to dentistry, but it does not replace gold until about 1910, following experimental work by Greene Vardiman Black [b. Winchester, Illinois, 1836, d. 1915] in 1895 that shows that mercury in amalgam is safe. *See also* 1771 MED.

❖ Physics

Essay on the Application of Mathematical Analysis to the Theories of Electricity and Magnetism by George Green

[b. Nottingham, England, July 14, 1793, d. Nottingham, May 31, 1841] introduces the theorem named after Green, which reduces certain volume integrals to surface integrals, making them easier to handle (rediscovered by several others before it enters mathematics).

1829

★ Astronomy

Nathaniel Bowditch begins publication of the English translation of *Mécanique céleste* by Pierre-Simon Laplace. *See also* 1799 AST.

❖ Chemistry

Jöns Jakob Berzelius discovers the chemical element thorium (Th), named after the Scandinavian god Thor.

The work of Thomas Graham [b. Glasgow, Scotland, December 21, 1805, d. London, September 16, 1869] with the diffusion of gases leads to the law named after him — that the rate of diffusion of a gas is inversely proportional to the square root of the gas's density.

Wolfgang Döbereiner describes the pattern of periodically returning characteristics of elements, a precursor of the periodic table. *See also* 1862 CHEM.

Peter Mark Roget develops a quantitative description of the chemical changes that take place in voltaic batteries during their discharge. *See also* 1824 COMM.

❖ Communication

Jacob Bigelow [b. Sudbury, Massachusetts, February 27, 1786, d. Boston, May 10, 1879] coins the term *technolo-*

gy in *The Elements of Technology*. *See also* 1833 COMM.

William Austin Burt [b. Worcester, Massachusetts, June 13, 1792, d. Detroit, August 18, 1858] patents an unwieldy but workable typewriter, the Typographer, for which the operator turns an arm to the correct letter and presses, inking the letter with a pad and pressing the letter on paper. *See also* 1714 COMM; 1833 COMM.

Charles Wheatstone [b. Gloucester, England, February 6, 1802, knighted 1868, d. Paris, October 19, 1875] invents the concertina (melodion), a bellows-operated instrument like the accordion, but with the two keyboards on each end of the bellows and with each reed playing the same note on both pumping actions. *See also* 1822 COMM.

According to some sources, Cyril Damian invents the accordion in Vienna, although others claim an earlier invention in Berlin. *See also* 1822 COMM.

❖ Earth science

Alexander von Humboldt travels to Siberia and explores the Altai mountains and Dzungarei.

French geologist Paul Desnoyers introduces the term Quaternary to describe recent time in the geologic time scale. *See also* 1760 EAR; 1833 EAR.

❖ Energy

Gas lighting is introduced in Paris. *See also* 1816 ENER.

❖ Food & agriculture

Rev. Patrick Bell [b. Dundee, Scotland, 1799, d. 1869] develops a grain reaping machine that is moderately successful.

See also 1810 FOOD; 1831 FOOD.

❖ Materials

Siméon-Denis Poisson introduces the constant of proportionality between primary and secondary stress now known as Poisson's ratio: If the primary stress and strain are compressive, the secondary strain will be tensile, while if the primary stress and strain are tensile, the secondary stress will be compressive. *See also* 1826 MATR; 1897 EAR.

Σ Mathematics

Nikolai Lobachevski's version of non-Euclidean geometry, the article "On the Principles of Geometry" in the *Kazan Messenger*, is the first to be published, although Janos Bolyai [b. 1802, d. 1860] reaches the same conclusion by this year and Gauss appears to have developed non-Euclidean ideas as early as 1816 without publishing them. *See also* 1826 MATH.

In May Evariste Galois presents his paper introducing group theory to the French Academy of Sciences, but Augustin Cauchy, who is to referee it, mysteriously does nothing about it; according to some sources, Cauchy loses the manuscript. *See also* 1830 MATH.

German mathematician and physicist Julius Plücker [b. Elberfeld, Duchy of Berg (Wuppertal, Germany), June 16, 1801, d. Bonn, Germany, May 22, 1868] proves the principle of duality for projective geometry; for any theorem you can exchange the words *point* and *line* and obtain a different theorem that is also true. *See also* 1826 MATH; 1831 MATH.

Non-Euclidean geometry

Even in Hellenistic times, Euclid's Fifth Postulate was viewed suspiciously. Euclid himself arranged his *Elements* so that the Fifth Postulate was not used in the first 25 propositions, although the 16th assumes something equivalent to it. The suspect postulate was much more complex and less self-intuitive than the other postulates, which are in the nature of, "through two distinct points one and only one straight line can be drawn." The Fifth Postulate states, "If a straight line falling on two straight lines makes the interior angles on the same side less than two right angles, the two straight lines if produced indefinitely meet on that side on which are the angles less than the two right angles." One objection to the Fifth Postulate was that the meeting point could be as far as one liked from the original line; in essence, the point could be infinitely far away. By the time of Proclus, 750 years after Euclid, geometers were bent on getting rid of this objectionable postulate.

There were essentially two strategies used: replacing the Fifth Postulate with a different equivalent postulate or establishing it as a mere theorem, a result proved from the other postulates. For the first strategy, the most common version of the postulate used is known today as Playfair's Postulate after the 18th-century version of British mathematician John Playfair. It states, "Through a given point, not on a given line, only one parallel can be drawn to the given line." Although Playfair's *Elements of Geometry* popularized this postulate, Proclus had also used it as an alternative to the Fifth Postulate in the fifth century. Playfair's postulate is a little easier to understand than Euclid's Fifth Postulate, but because the two postulates are equivalent, it is just as suspect. Two postulates are equivalent when each one implies the other.

The second strategy also involves equivalent postulates. For each time that someone tried to prove the Fifth Postulate as a theorem, it was found that he had to invoke a result that was equivalent to the Fifth Postulate. These equivalent postulates include "a line that intersects one of two parallel lines intersects the other"; "the sum of the angles of a triangle is 180°"; "for any triangle there exists a similar triangle not congruent to the first triangle"; and "there exists a circle passing through any three noncollinear points." Invoking any of these in a proof of the Fifth Postulate amounts to circular reasoning since each is equivalent to the Fifth Postulate.

In the 18th century, Girolamo Saccheri suggested a third strategy, indirect proof of the Fifth Postulate by contradiction. He assumed that one of the equivalents to the Fifth Postulate is *not* true. There are two ways in which this equivalent postulate could be not true, so Saccheri needed to deal with two assumptions. Saccheri developed a number of geometric theorems from each of these assumptions combined with Euclid's other postulates, looking for a contradiction between two of these new theorems. Finding such a contradiction from one assumption would mean that either the Fifth Postulate or the other assumption had to be true. Saccheri convinced himself that he had found such contradic-

tions for both assumptions, leaving the truth of the Fifth Postulate the only remaining possibility. His report of his efforts was called *Euclides ab omni aaevo vindicatus* (sometimes translated into English as *Euclid Freed of Every Fleck*)

When he was 15, Karl Friedrich Gauss began to work on the problem of the Fifth Postulate. Gauss recapitulated the approaches of others with the same results, except that he was better than they had been at seeing that his attempted proofs did not work. After 25 years of working on the problem, he evidently reached the conclusion that the Fifth Postulate is independent of the others. This means that a contradiction to the Fifth Postulate can be used to develop a consistent geometry. Gauss proceeded to do this to his own satisfaction, but did not publish his work, although he told a few friends about his conclusion.

Shortly after (during the late 1820s), two other gifted mathematicians also reached the conclusion that the Fifth Postulate is independent of the others. Both Nikolai Ivanovich Lobachevski and Janos Bolyai independently discovered and published their non-Euclidean geometries. In all three versions (including that of Gauss), the mathematicians assumed that more than one line passing through the same point could be parallel to another line.

In 1854 Bernhard Riemann suggested that there were several non-Euclidean geometries. For example, one could avoid the contradictions of Saccheri's first assumption by changing Euclid's first and second postulates along with the fifth. The result appeared to be consistent — that is, no contradictory theorems can arise.

In short order, Eugenio Beltrami was able to prove that the original non-Euclidean geometry of Lobachevski and Bolyai is consistent if Euclidean geometry is itself consistent. Felix Klein soon showed that two different versions of Riemann's geometry were as consistent as Euclid's. The method employed in each case was to find a model of the non-Euclidean geometry that was within Euclid's geometry. The easiest such model to understand takes the surface of a sphere as the plane, which is undefined in the modern treatment of Euclidean geometry. Then if great circles are taken to be lines, they obey such postulates as "two distinct points determine at least one line" (replaces Euclid's First Postulate); "a straight line is finite in length" (replaces Euclid's Second Postulate), and "no two lines are parallel" (replaces Euclid's Fifth Postulate). The new postulates not only describe Riemann's form of non-Euclidean geometry, they also accurately describe geometry on a sphere (with the understanding that a line is really a great circle); but geometry on a sphere can also be described by Euclid's original postulates when great circles are understood as circles, not lines.

Despite the mathematical validity of non-Euclidean geometries, they were not deemed of much practical value until 1915, when Albert Einstein and Hermann Minkowski showed that gravity could be explained by treating space as a four-dimensional Riemann-type geometry. In other words, space itself is non-Euclidean, despite our impression of it. This is because we view it on a small scale. On a small scale, Earth looks flat. On a larger scale, with a different definition of line, it is non-Euclidean.

Evariste Galois

[b. Bourg-la-Reine, France, October 25, 1811, d. Paris, May 31, 1832]

Galois died young with almost none of his work published or even read during his lifetime. In 1846 his papers and a letter describing his main discovery were edited and published. His main discovery was that equations of degree 5 or higher cannot be solved using the ordinary tools of algebra. But the method he used to reach the conclusion was more influential than the theorem. The method, group theory, has been at the core of mathematical thought for the past century and a half.

Heart Medicine & health

Johann Lukas Schönlein [b. November 30, 1793, d. 1864] describes hemophilia, a genetic disease that produces blood that does not clot.

James Mill [b. Fofarshire, Scotland, April 6, 1773, d. London, June 23, 1836] publishes *Analysis of the Phenomena of the Human Mind*, which tries to show that the mind is nothing more than a machine and that it has no creative function. See also 1758 MED; 1923 MED.

Physics

Joseph Henry [b. Albany, New York, December 17, 1777, d. Washington, DC, May 13, 1878] completes a four-year study of the electromagnet during which he discovers the law of proportion between electromotive force and resistance of the magnet. Henry works out the effects of different types of windings for electromagnets. He shows that wire wrapped into coils produces a greater magnetic field when an electric current goes through it than a straight wire

does and that an insulated wire wrapped around an iron core can produce a powerful electromagnet. See also 1824 PHY; 1831 COMM.

Physicist André-Marie Ampère classifies the science of mechanics into *statics*, the study of bodies at rest, and *kinematics*, the study of bodies in motion, two definitions still in use today. Gustave-Gaspard de Coriolis [b. Paris, May 21, 1792, d. Paris, September 19, 1843] coins the term *kinetic energy* in *On the Calculation of Mechanical Action*

I Tools

The first electromagnetically driven clock is made. See also 1840 TOOL.

→ Transportation

The Welland Canal in Canada is constructed to bypass the Niagara River between lakes Erie and Ontario, which includes among its rapids the famed Niagara Falls. See also 1821 TRAN.

1830**★ Astronomy**

The Mechanisms of the Heavens by Mary Fairfax Somerville [b. Jedburgh, Scotland, December 26, 1780,

d. Naples, Italy, November 29, 1872] is a popularization in English of Laplace's *Mécanique céleste*. Although Somerville is self-educated, Laplace declares that she is the only woman to have understood his work. See also 1799 AST; 1831 MATH.

◊ Chemistry

Pierre Louis Dulong [b. Rouen, France, February 12, 1785, d. Paris, July 19, 1838] determines the percentages of hydrogen and carbon in organic compounds by his perfected incineration method. See also 1833 CHEM.

Jöns Jakob Berzelius coins the term *isomerism* to describe compounds of identical chemical composition but different structure and properties, first identified by Joseph Louis Gay-Lussac. See also 1824 CHEM; 1848 CHEM.

◆ Communication

James Perry [b. Banbury, England, 1769, d. 1843] develops an improved form of the steel pen point, or nib, that is made flexible by cutting slits in the body of the point and adding a hole; this form of pen becomes the commonplace type for the next hundred years. See also 1822 COMM; 1938 COMM.

Trains start carrying mail in England between cities; previously, the bulk of mail was carried by coaches. See also 1784 COMM; 1840 COMM.

⊕ Earth science

The first volume of *The Principles of Geology* by geologist Sir Charles Lyell begins a massive study that shows Earth must be several hundred million years old. Volume three is published in 1833, and the whole trilogy is republished many times since, with a dozen revisions during the author's lifetime. See also 1654 EAR; 1907 EAR.

William Nicol [b. Scotland, 1768, d. Edinburgh, September 2, 1851] begins work on what will eventually become the petrological microscope, a device for viewing thin sections of rock. Nicol's first experiments use thin sections of wood, however.

↗ Energy

Joseph Henry discovers the principle of electromagnetic induction shortly before Michael Faraday does, but fails to publish; he publishes his results after learning of Faraday's. He also describes a practical electric motor. See also 1829 PHY; 1831 ENER.

Sir Charles Lyell

[b. Kinnordy, Scotland, November 14, 1797, d. London, February 22, 1875]

Lyell is known as the principal advocate of uniformitarianism, the doctrine first propounded by James Hutton a dozen years before Lyell's birth. Lyell's *Principles of Geology*, first issued starting in 1830 and revised a dozen times, changed geology; it was an important influence on Darwin as was Lyell himself, a good friend to Darwin throughout Darwin's adult life. Lyell's other work, *The Antiquity of Man*, issued in 1863, explored the implications of Darwinian evolution for humans.



French chemistry student Charles Sauria [b. 1812, d. 1895] discovers how to make matches that light when struck, using yellow phosphorus, sulfur, and potassium chlorate. Jacob Friedrich Kammerer manufactures them. *See also* 1827 ENER; 1855 ENER.

S Mathematics

Treatise on Algebra by George Peacock [b. Durham, England, April 9, 1791, d. Ely, England, November 8, 1858] is one of the first attempts to formulate the fundamental laws of numbers. *See also* 1879 MATH.

In February Evariste Galois presents a second version of his theory of groups to the French Academy of Sciences, but the referee, Jean-Baptiste Fourier, dies before looking at it. The document is never found among Fourier's papers. *See also* 1829 MATH; 1831 MATH.

♥ Medicine & health

Charles Bell's *The Nervous System of the Human Body* distinguishes different types of nerves. *See also* 1822 MED; 1833 MED.

Physiologist Marshall Hall [b. Basford, England, February 18, 1790, d. Brighton, England, August 11, 1857] is the first to identify and study reflexes. He also denounces bloodletting as a treatment for disease.

I Tools

Richard Roberts [b. Llanymynech, Montgomeryshire, Wales, 1789, d. 1864] develops the automatic, or self-acting, spinning mule, which, unlike the original version, can be operated easily by semiskilled workers. *See also* 1779 TOOL.

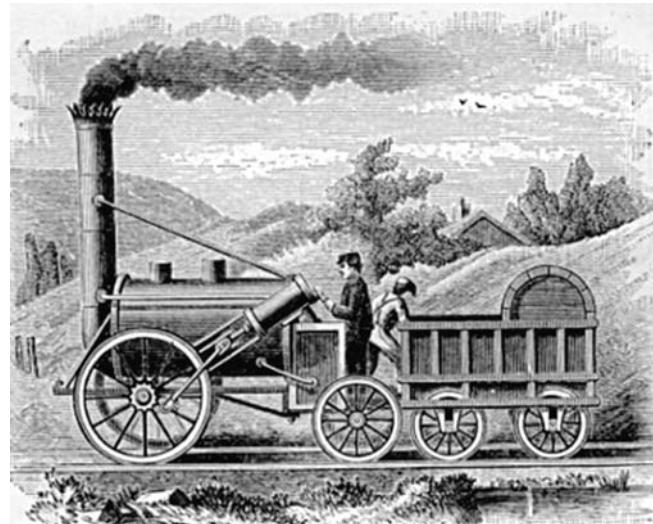
Optician Joseph Jackson Lister [b. London, January 11, 1786, d. West Ham, Essex, England, October 24, 1869] succeeds in developing an achromatic lens for the microscope about 70 years after the first achromatic telescope lenses were made. *See also* 1762 TOOL; 1834 TOOL.

French tailor Barthélemy Thimonnier [b. 1793, d. 1859] invents a sewing machine and installs 80 of them in a workshop for military clothing. The following year his workshop is destroyed by Parisian tailors fearing to be put out of work. *See also* 1846 TOOL.

In Stroud, England, Edwin Beard Budding [b. 1796, d. 1846] invents the reel (or cylinder) lawn mower, basing it on a device used to make a smooth nap on cloth. Before this, lawns were cut with scythes, which left grass high and ragged. The mower is patented and manufactured by his partner, engineer John Ferrabee. *See also* 1902 TOOL.

→ Transportation

In October George Stephenson's steam locomotive The Rocket is chosen over three competitors to open the Liverpool to Manchester railway. *See also* 1825 TRAN; 1832 TRAN.



GEORGE STEPHENSON'S ROCKET LOCOMOTIVE AND TENDER The Rocket demonstrated its superiority over other early locomotives, first by hauling a coach with 30 passengers at a speed of 40 to 50 km (25 to 30 mi) per hour and then, two days later, reaching a top speed of 47 km (29 mi) per hour while pulling 13 tons of freight. On one occasion, after it had been in service at two different rail lines for several years, the Rocket reached a speed exceeding 80 km (50 mi) per hour.

1831

Biology

Charles Darwin joins the crew of the H.M.S. *Beagle* as the ship's naturalist. The *Beagle* is about to start a planned two-year voyage mapping the coast of South America.

Charles Robert Darwin

[b. Shrewsbury, England, February 12, 1809, d. Down, Kent, England, April 19, 1882]

The 1859 publication of *On the Origin of Species*, in which Darwin demonstrated that all living things evolved from earlier forms of life by the process of natural selection, revolutionized human thought. Although initially controversial, Darwin's theory of evolution, which also was set forth by Alfred Wallace, became accepted as one of the foundations of modern biology. Darwin originally believed in the orthodox theory of his time: that each species had been created individually and had remained unchanged since Earth's beginning. But his observations of fossils and living organisms during a five-year voyage around the world aboard H.M.S. *Beagle* (1831–36) led to his conclusion that new species arose as existing species gradually changed in response to environmental conditions. Among his best-known evidence was the adaptive radiation of finches he studied on the Galapagos Islands.



This becomes a five-year voyage that enables Darwin to observe the significant differences among closely related species. *See also* 1768 EAR; 1835 BIO.

Robert Brown discovers and names the nucleus of the cell. Literally *nucleus* means “little nut,” but the term was already in use by botanists for a central body within a seed. *See also* 1665 BIO; 1835 BIO.

Chemistry

Nils Gabriel Sefström [b. Hälsingland, Sweden, June 2, 1787, d. Stockholm, Sweden, November 30, 1845] rediscovers vanadium (V), which had been discovered in 1801 by Andrès Del Rio, but Del Rio was persuaded by other chemists that he had merely rediscovered chromium. Eventually Friedrich Wöhler will sort all this out.

French pharmacologist Eugène Soubeiran [b. 1793, d. 1858], German chemist Justus von Liebig, and American chemist Samuel Guthrie [b. Brimfield, Massachusetts, 1782, d. Sackett's Harbor, New York, October 19, 1848] independently discover chloroform. Guthrie develops a process for producing it.

Communication

Joseph Henry develops the first electromagnetic telegraph; he sends an electric charge through 1500 kilometers of wire, where an electromagnet produces a force on a suspended permanent magnet that swivels and rings a bell. *See also* 1809 COMM; 1832 COMM.

Construction

Isambard Kingdom Brunel [b. Portsmouth, England, April 9,

1806, d. Westminster, England, September 7, 1859] designs a suspension bridge to pass over the river Avon at Clifton, England, but the bridge is not actually built until 1864. *See also* 1825 CONS.

Earth science

On May 31 Scottish explorer James Clark Ross [b. London, April 15, 1800, d. Aylesbury, England, April 3, 1862] reaches the magnetic North Pole on Boothia Peninsula in northern Canada. *See also* 1909 EAR.

Energy

William Avery builds and sells steam turbines consisting of two jets mounted on a rotating hollow shaft. Steam flows through the jets and the shaft rotates because of the reactive force of the steam; 50 of these turbines find applications in workshops. *See also* 60 CE ENER; 1849 ENER.

On August 29 Michael Faraday independently rediscovers Joseph Henry's earlier (unpublished) finding that electricity can be induced by changes in a magnetic field (called electromagnetic induction), a discovery that leads directly to the first generators (a.k.a. dynamos). Unlike Henry, Faraday communicates his result to the Royal Society on November 24. Faraday's device is often called the first electric generator; it produces direct current. *See also* 1830 ENER; 1832 ENER.

Jacob Perkins patents an air-conditioning system that uses cold air from underground tunnels. *See also* 1837 ENER.

Food & agriculture

Cyrus Hall McCormick [b. Walnut Grove, Virginia, February 15, 1809, d. May 13,

1884] demonstrates his first version of the reaper in July. *See also* 1836 FOOD.

Materials

Pierre-Jean Robiquet and Jean Jacques Colin [b. Riom, France, December 16, 1784, d. March 9, 1865] discover the red dye alizarin. *See also* 1771 CHEM; 1868 CHEM.

Mathematics

Gauss warns that the actual infinite (as opposed to the potential infinite) must be kept out of mathematics, which would then be able to stay free of contradictions. The actual infinite would be an infinite collection of objects, whereas the potential infinite occurs when one can establish that for any large number of objects there will always be at least one more that has not yet been included. *See also* 1850 MATH.

In January Evariste Galois presents a third version of his paper on group theory, now titled *Une mémoire sur les conditions de résolubilité des équations par radicaux* (“a note on the conditions under which equations can be solved by using radicals”) to the French Academy of Science, where it is rejected by referee Simeon-Denis Poisson as not sufficiently clear. *See also* 1830 MATH; 1833 MATR.

Belgian astronomer and statistician Lambert-Adolphe Jacques Quetelet [b. Ghent, Flanders (Belgium), February 22, 1796, d. Brussels, February 17, 1874] studies how such factors as sex, age, education, climate, and season affect the crime rate in France. *See also* 1761 MATH; 1841 MATH.

Julius Plücker extends the

principle of duality to three dimensions, where the words *point* and *plane* can be interchanged to produce new theorems, while the word *line* remains unchanged. *See also* 1829 MATH.

Augustin Cauchy establishes the criteria permitting an analytic function of a complex variable to be expanded about a point in a power series, the essential step in permitting mathematicians to solve problems of all kinds by converting them to infinite series. Such series can then be used to work term by term toward a complete solution or to be truncated to give approximate solutions. *See also* 1822 MATH; 1874 MATH.

Tools

William Bickford [b. Devonshire, England, 1774, d. 1834] patents the safety fuse for explosives, which consists of 12 strands of spun yarn with black powder funneled into the center. *See also* 1833 MATR.

Transportation

Walter Hancock [b. 1799, d. 1852] introduces a steam-powered ten-seat bus that travels between London and Stratford. *See also* 1801 TRAN; 1835 TRAN.

1832

Chemistry

Jean-Baptiste-André Dumas and Auguste Laurent [b. St. Maurice, Haute Marne, France, November 14, 1807, d. Paris, April 23, 1853] discover anthracine in coal tar. *See also* 1819 CHEM; 1834 CHEM.

Communication

Russian diplomat Baron Pavel Schilling [b. c. 1780, d. 1836]

uses a telegraph with rotating magnetized needles to link the summer palace of the czar in Saint Petersburg to his winter palace. *See also* 1831 COMM; 1833 COMM.

Joseph Antoine Plateau [b. Brussels, Belgium, October 14, 1801, d. Ghent, Belgium, September 15, 1883], who has studied the retinal retention of the eye, develops the phenakistiscope. It consists of two disks mounted on a single axis, one carrying several still images of an object or person in motion that can be observed through slits in the other disk; by rotating the disks and observing the images through the slits, the illusion of motion is created. *See also* 1825 COMM; 1891 COMM.

Computers

Charles Babbage conceives of the first computer, the Analytical Engine. It is a mechanical calculating machine driven by an external set of instructions or program; although strikingly modern in concept, the computer is never built in workable form. *See also* 1822 COMP; 1936 COMP.

Construction

Joseph Paxton [b. Woburn, England, August 3, 1801, d. Sydenham, England, June 8, 1865], while remodeling a greenhouse roof, is the first to use the concept of ridge-and-furrow construction. The idea of this system is owed to John Claudius Loudon [b. Cambuslang, Scotland, 1783, d. Battersea, England, December 14, 1843]. The bases of the V-shaped furrows and the vertices of their ridges each act as beams. The result is stronger than a roof of the same thickness that does not use the construction, which in

appearance is rather like corduroy (although in this instance, made from glass). *See also* 1841 CONS.

Energy

Joseph Henry discovers self-induction, or inductance, the second current in a coil through which one current is passing that is induced by the first current. He publishes a paper about a spark that can be produced by this effect, but the effect is not described until 1835, when Michael Faraday independently rediscovers it. Because of Henry's priority, the unit of inductance is known as the henry; note that *inductance*, discussed here, is not the same as *induction*, discovered independently by Henry and Faraday in 1831. *See also* 1831 ENER; 1835 ENER.

French instrument maker Hippolyte Pixii [b. 1808, d. 1835] demonstrates a hand-driven "magneto-electric machine," a generator in which a horseshoe magnet rotates in front of two coils. This is believed to have been the first continuously acting current generator to produce alternating current (Faraday's generator of 1831 produced direct current). *See also* 1831 ENER; 1838 ENER.

Mathematics

The appendix by Janos Bolyai [b. Kolozsvár, Hungary, December 15, 1802, d. Marosvásárhely, Hungary, January 17, 1860] to his father's *Tentamen*, called the *Appendix scientiam spatii absolute veram exhibens* ("appendix explaining the absolute science of space"), is the second published account of non-Euclid-

ean geometry. *See also* 1829 MATH; 1854 MATH.

Mary Fairfax Somerville's *A Preliminary Dissertation on the Mechanisms of the Heavens* provides the mathematical background necessary to understand her popularization of Laplace's *Mécanique céleste*. *See also* 1830 AST.

Jakob Steiner [b. Utzenstorf, Switzerland, March 18, 1796, d. Bern, Switzerland, April 1, 1863], considered the greatest geometer of his time, publishes *Systematische Entwicklungen*, basing projective geometry on measurement. Steiner, among many other discoveries, shows that all constructions possible with a straightedge and compass are equally possible with just a straightedge and a single given circle. *See also* 1829 MATH; 1847 MATH.

Medicine & health

French Chemist Pierre-Jean Robiquet discovers codeine. *See also* 1805 CHEM.

Thomas Hodgkin [b. Tottenham, England, August 17, 1798, d. Tel-Aviv (Israel), April 5, 1866] gives a description of Hodgkin's disease, a cancer of the lymph nodes.

The Warburton Anatomy Act legalizes the sale of bodies for dissection in England, ending the practice of body snatching and sometimes murder to provide bodies.

Dentists' chairs that recline are constructed, but manufactured versions do not become available until late in the 1860s. *See also* 1790 MED.

Tools

The first rope-drilled artesian well, using a method of drilling originally developed

by the Chinese 800 years previously, is drilled in Europe. The well is 547 m (1795 ft) deep at Grenelle, France, near Paris. As in all artesian wells, the water source is under pressure that pushes the water to the surface when the well reaches it. *See also* 1126 TOOL; 1858 TOOL.

John Ireland Howe [b. Ridgefield, Connecticut, July 20, 1793, d. Derby, Connecticut, September 10, 1876], using the shop of printing-press manufacturer Richard Hoe, builds a working model of a machine that can make straight pins in a single mechanized operation, which he patents. *See also* 1835 TOOL.

Transportation

Austrian engineer Franz Anton von Gerstner [b. 1756, d. 1832] designs the first railroad passenger cars, but these cars are drawn by horses. They look very much like coaches except for the wheels. *See also* 1830 TRAN. 1840 TRAN.

1833

Astronomy

On the night of November 12–13 a great meteor shower hits the United States, causing astronomers to inquire into the causes of such showers. Some 8000 meteors — also called shooting stars — are seen over Boston during one period of 15 minutes. It is the Leonids shower, caused as Earth passes each year through the tail of comet Tempel-Tuttle. The meteors are the display caused when tiny dust particles strike the atmosphere at high speed. The Leonids shower varies in intensity depending on where the comet, which has a period

of 33 years, is in relationship to Earth. *See also* 1799 AST.

﴿ Biology

The first volume of the five-volume *Recherches sur les poissons fossiles* (“researches on fossil fishes”) by Swiss-American naturalist Jean-Louis-Rudolphe Agassiz [b. Môtier, Switzerland, May 28, 1807, d. Cambridge, Massachusetts, December 12, 1873] is published.

Anselme Payen discovers the first enzyme, diastase, an extract of malt that speeds the conversion of starch to sugar. *See also* 1836 BIO.

﴿ Chemistry

Jean-Baptiste-André Dumas develops a method for determining the nitrogen content of organic compounds. *See also* 1830 CHEM; 1834 CHEM.

﴿ Communication

William Whewell [b. Lancaster, England, May 24, 1794, d. Cambridge, England, March 6, 1866] coins the term *scientist* at a meeting of the British Association for the Advancement of Science and popularizes his new word further in *The Philosophy of the Inductive Sciences*. Gauss and Wilhelm Weber [b. Wittenberg (Germany), October 24, 1804, d. Göttingen, Germany, June 23, 1891] build an electric telegraph operating over a distance of 2 km (1.25 mi). As a receiving device it uses a “mirror” galvanometer with a needle that moves when current flows. *See also* 1832 COMM; 1835 COMM.

French inventor Xavier Progin builds a typewriter in which letters are mounted on independent hammers and inked by an inkpad. It is the first

typewriter with a manual keyboard. He also develops a typesetting machine. *See also* 1829 COMM; 1843 COMM.

In October William Henry Fox Talbot [b. Dorsetshire, England, February 11, 1800, d. Lacock Abbey, Wiltshire, England, September 17, 1877] independently conceives of photography while experimenting with the camera obscura. *See also* 1822 COMM; 1834 COMM.

﴿ Earth science

Scholar William Whewell introduces the word *uniformitarianism* to name the principle that inferences about past geologic events should be confirmed by slow-acting, low-magnitude processes that are currently observable. *See also* 1785 EAR.

Gauss and Wilhelm Weber in Göttingen found the first magnetic observatory.

Charles Lyell identifies the Recent, Pliocene, Miocene, and Eocene periods in Earth’s history. *See also* 1822 EAR.

﴿ Energy

John Ericsson [b. Varmland, Sweden, July 31, 1803, d. New York, March 8, 1889] builds a heat engine that uses superheated air as the driving force and that produces 5 horsepower. He publishes a description of his machine, *The Caloric Engine*. *See also* 1817 ENER.

﴿ Food & agriculture

American inventor Obed Hussey [b. Maine, 1792, d. while traveling from Boston to Portland, August 4, 1860] patents a reaper based on reciprocating knives cutting

against stationary guards. *See also* 1831 FOOD; 1834 FOOD.

Illinois blacksmith John Lane [b. New York, 1793, d. 1857] produces a plow made from wood covered with steel strips cut from a saw blade. It proves to be better for plowing Midwestern prairie soils than the cast-iron plows that are effective in the eastern United States. *See also* 1819 FOOD; 1837 FOOD.

﴿ Materials

The first new explosives since gunpowder (“black powder”) are the family of nitrogen explosives. They have their origin in the discovery this year by French chemist Henri Braconnot [b. Commercy, France, May 29, 1781, d. Nancy, France, January 13, 1855] of a flammable nitric acid ester or starch. *See also* 1807 CHEM; 1838 MATR.

Michael Faraday produces aluminum by electrolysis. *See also* 1828 MATR; 1855 MATR.

﴿ Mathematics

Adrien-Marie Legendre’s *Réflexions sur différentes natures de démontrations de la théorie de parallèles* (“reflections on different ways to prove the theory of parallels”) summarizes a dozen faulty proofs of Euclid’s Fifth, or Parallel, Postulate. *See also* 1832 MATH; 1854 MATH.

Evariste Galois is shot in a duel over a personal matter on May 30. He leaves behind a summary of his paper on group theory addressed to a friend. Galois dies the next day. *See also* 1831 MATH; 1843 MATH.

﴿ Medicine & health

Handbuch der Physiologie by Johannes Peter Müller [b.

Koblenz (Germany), July 14, 1801, d. Berlin, April 28, 1858] summarizes physiological research of the period. It also puts forth the theory that each nerve contains its own specific energy. *See also* 1830 MED; 1838 MED.

﴿ Physics

Michael Faraday introduces the laws of electrolysis; that is, the amount of substance decomposed by an electric current is proportional to the length in time and amount of electric current producing electrolysis. In correspondence Faraday and William Whewell introduce the terms *electrode*, *anode*, *ion*, *cathode*, *anion*, *cation*, *electrolyte*, and *electrolysis*. *See also* 1807 CHEM; 1853 CHEM.

Russian physicist Heinrich Friedrich Emil Lenz [b. Tartu, Estonia, February 24, 1804, d. Rome, February 10, 1865] discovers that the resistance of a metallic conductor increases as temperature is raised and decreases as temperature is lowered. *See also* 1827 ENER; 1834 PHY.

1834

﴿ Archaeology

Archaeologist Christian Jorgensen Thomsen [b. Copenhagen, Denmark, December 29, 1788, d. Copenhagen, May 21, 1865] divides the time people have existed into a Stone Age, a Bronze Age, and an Iron Age.

Architect Leo Klenze [b. (Germany), 1784, d. 1864] begins restoration of the temples of the Acropolis in Athens to something like their original appearance. *See also* 1801 ARCH.

Galois and group theory

Popular legend has it that 20-year-old Evariste Galois, thinking he might be killed in a duel over a woman's honor, invented group theory — one of the most basic and important concepts of modern mathematics — on the night of May 29, 1832. Galois used his new concept to prove that equations of the fifth degree — quintics — and higher could never be solved. He was indeed killed the following day, but because his ideas were so radical it took 150 years for mathematicians to work out their implications.

It is a dramatic legend, but almost entirely untrue. Paolo Ruffini proved that the general quintic could not be solved by algebraic means before Galois was born, and independently Niels Abel gave an even better proof in 1824. Although Galois contributed to group theory he cannot lay claim to being its inventor. The notes he wrote out that night were not new mathematics; over the previous five years Galois had submitted three versions of the same material to the French Academy, but two great mathematicians had managed to ignore or misplace the first two versions, and the third was turned back for lack of clarity; it is even unlikely that the duel was over a woman's honor.

Group theory can be traced back to origins in geometry, number theory, and permutations, as well as the algebraic studies of Ruffini, Abel, and Galois, although it was Galois who first used the term *group*. Possibly the earliest use of group theoretic ideas was by Leonhard Euler in 1761 in a paper on number theory, although Euler did not explicitly label the concepts as anything special.

Later, a group was defined as a set of objects that obeys four simple rules for a given operation. For the mathematically inclined, groups are closed and associative and possess an identity element and inverses with respect to it: *Closed* means that when two elements of a group are combined by the group operation, another element of the group always results. *Associative* means that three elements can be combined starting with either the first pair or the second pair of the three and the result does not change. The *identity element* is a member of the group that does not change an element combined with it. *Inverses* are pairs of elements that when combined produce the identity element. An example of a group is the positive and negative integers where the operation is addition and the identity element is zero. A finite group might consist of all the transformations that bring a capital letter of the alphabet, other than O, into itself: A remains the same when reflected, I or H when reflected or turned 180°, N when turned but not when reflected, etc.

Galois' accomplishment, while misrepresented in popular leg-

end, was quite real. Nearly 20 years after his death, the concepts of group theory had advanced enough so that his obscurely written paper could be clearly understood. He had developed a general method for determining the solvability of equations, going considerably beyond Ruffini and Abel. Along the way, he had independently created large chunks of group theory.

Group theory came to pervade all of mathematics. In 1872 Felix Klein suggested that different types of geometry be defined in terms of groups in his famous Erlangen Program. This was largely accomplished in the late 19th and early 20th centuries. In fact, a purely geometric concept, such as topology (the branch of geometry concerned with connections rather than shapes), evolved to produce a purely algebraic theory of topology based on groups. Modern algebra books introduce groups in the early chapters and use the concept thereafter. Even branches of mathematics with no explicit use of group theory are structured in ways that emerged from the theory. One textbook that addresses all of classical mathematics states in its introduction, "If a person is not ready and anxious to explore the concept of a group further, we recommend that he reconsider his relationship to mathematics."

Despite its pervasive influence in mathematics, group theory was not seen as particularly useful in applications until recently. Although it was suggested as a tool in chemistry, nothing much emerged. Crystallographers were the main beneficiaries outside of mathematics. Then, in 1926, Eugene Paul Wigner introduced groups to particle physics. After World War II, a number of physicists began to think about how group theory could be used. In the early 1960s Sheldon Glashow, Murray Gell-Mann, and others discovered that group theory enabled them to predict the properties of particles before the particles were observed and to make sense out of the many new particles that were being discovered. By the 1980s a "standard model" of particle physics had emerged based on group theory, and physicists were using groups as a tool in trying to develop grand unified theories (GUTs) that combine all the known forces except gravity. The even more ambitious superstring theory, which includes gravity, is also based on groups.

Meanwhile, the very mathematicians who specialized in one part of pure group theory worked themselves out of a job. It had become apparent that there were only a finite number of simple groups that have a finite number of members. (Roughly speaking a simple group is one without a certain class of subgroups.) Group theorists doggedly worked out each possible group in succession. Finally, in 1980, Robert L. Griess, Jr. worked out the last possible finite group, nicknamed the "monster" because it is so large.

★ Astronomy

Ernst Weber discovers the law governing the perceptions of the eye and ear. German physicist Gustav Theodor Fechner [b. Grossaerchen (Germany), April 19, 1801, d. Leipzig, Germany, November 18, 1887] applies it to stellar magnitudes in astronomy and popularizes the rule, now known as the Weber-Fechner law: The percentage difference in intensity is more important in perception than absolute differences. *See also* 1856 AST.

Marie-Charles-Théodore Damoiseau publishes *Tables écliptiques des satellites de Jupiter* ("eclipse tables of Jupiter's satellites"), which gives the exact times when the moons of Jupiter are eclipsed by passing behind the giant planet. Comparing these times with local time (determined by the Sun) is the best way available at this time to determine longitude. *See also* 1824 AST.

The British Admiralty publishes the first "modern" nautical almanac. *See also* 1802 TRAN; 1857 AST.

◆ Biology

German-Swiss physiologist Gabriel Gustav Valentin [b. Breslau (Wrocław, Poland), July 8, 1810, d. Bern, Switzerland, May 24, 1883] and Johannes Purkinje discover that cilia in the oviduct move the ovum from place to place. *See also* 1651 BIO.

□ Chemistry

German chemist Friedlieb Ferdinand Runge [b. February 8, 1795, d. March 25, 1867] discovers phenol (carbolic acid) in coal tar. *See also* 1832 CHEM; 1858 MATR.

Jean-Baptiste-André Dumas

formulates his Law of substitution: Halogens can replace hydrogens in organic compounds. *See also* 1833 CHEM; 1836 CHEM.

German chemist Robert Wilhelm Bunsen [b. Göttingen (Germany), March 31, 1811, d. Heidelberg, Germany, August 16, 1899] discovers an antidote to arsenic poison.

The British Association for the Advancement of Science recommends the adoption of the system of chemical symbols devised by Jöns Jakob Berzelius. *See also* 1828 CHEM.

Anselme Payen extracts cellulose from wood and names it. *See also* 1855 MATR.

◆ Communication

In August John Scott Russell [b. Parkhead, Scotland, May 8, 1808, d. Isle of Wight, June 8, 1882] observes a peculiar wave caused by a barge in the Union Canal near Edinburgh, Scotland. Unlike an ordinary water wave, this single 9-m- (30-ft-) long, 0.5-m- (1.5-ft-) high wave does not quickly dissipate, but maintains a constant speed of about 13 to 14 km (8 to 9 m) per hour for several kilometers before Russell, who is following it on horseback beside the canal, loses it. The event is the first recorded observation of a soliton, a type of wave that will be applied to optical-fiber communications about 150 years later. *See also* 1980 PHY.

William George Horner [b. Bristol, England, 1786, d. Bath, England, September 22, 1837] develops the Zoetrope, a motion-picture device that is an improvement on Joseph Plateau's phenakistiscope. He introduces it to the United

States in 1867. *See also* 1832 COMM.

In January William Fox Talbot begins experiments with silver nitrate. These eventually lead to the development of photography. *See also* 1833 COMM; 1835 COMM.

□ Computers

Swedish engineer Pehr Georg Scheutz [b. 1785, d. 1873] and his son Edward [b. 1821, d. 1881] build the first of several copies of the Difference Engine that was designed by, but never built by, Charles Babbage. *See also* 1822 COMP.

● Earth science

Friedrich August von Alberti [b. 1795, d. 1878] identifies the Triassic period in Earth's history. *See also* 1833 EAR; 1835 EAR.

▼ Energy

Johann Georg Bodmer [b. Zurich, Switzerland, December 6, 1786, d. Zurich, May 29, 1864] patents the traveling-grate stoker. It is improved by John Juckles in 1841; the improved version is known as the chain-grate stoker. It becomes the most widely used stoker for steam boilers.

William Edwards Staite begins experimenting with electric arc lamps. *See also* 1836 ENER.

■ Food & agriculture

In Switzerland, Jacob Sulzberger improves the design of roller mills, which had not previously been widely accepted by millers. *See also* 1662 FOOD.

Inventors John Pitts [b. Clinton, Maine, 1799, d. Buffalo, New York, 1859] and his twin Hiram [d. Chicago, 1860] develop the first efficient

threshing machine. *See also* 1784 FOOD.

Σ Mathematics

Sir William Rowan Hamilton transforms the Lagrange formulas known as Lagrangians into the form of "canonical equations" now called Hamiltonians. These describe motion in terms of action and become one of the main tools of mathematical physics. *See also* 1788 PHY.

❖ Physics

Heinrich Lenz discovers that a current induced by electromagnetic forces creates a current flow that opposes those forces, now known as Lenz's law.

Engineer Benoit-Pierre Clapeyron [b. Paris, February 26, 1799, d. Paris, January 28, 1864] develops the first version of the second law of thermodynamics (often expressed as entropy tends to increase in a closed system) on the basis of his study of the thermodynamics of steam engines. The law is later generalized by Rudolf Clausius. *See also* 1850 ENER.

Jean Charles Athanase Peltier [b. Ham, France, February 22, 1785, d. October 27, 1845] discovers the "Peltier effect," that a current flowing across a junction of dissimilar metals causes heat to be absorbed or freed, depending on the direction the current is flowing. *See also* 1821 PHY.

☒ Tools

Peter Barlow [b. Norwich, England, October 13, 1776, d. Kent, England, March 1, 1862] describes lenses with variable magnification. *See also* 1830 TOOL.

1835

★ Astronomy

Comet Halley makes its second predicted return. It is first spotted on August 5 by Father Dumouchel and Francesco de Vico [b. Macerata, States of the Church (Italy), May 19, 1805; d. London, November 15, 1848] of the Roman Collega observatory in Rome. *See also* 1758 AST.

Galileo's *Dialogue Concerning the Two Chief World Systems* is removed from the Index of Prohibited Books of the Roman Catholic Church.

Philosopher Auguste Marie François Xavier Comte [b. Montpellier, France, January 19, 1798, d. September 5, 1857] declares (incorrectly) that knowledge of the chemical composition of stars will forever be denied to man. *See also* 1863 AST.

Biology

Lambert-Adolphe Quetelet's *Anthropometrie* uses measurements to determine that physical sizes of body parts fall into what we now recognize as the normal curve. *See also* 1733 MATH.

Darwin, while scientific officer on the voyage of the *Beagle*, visits the Galápagos Islands. He observes that closely related finches (known today as Darwin's finches) seem to have developed from a common ancestor found on the mainland of South America, the nearest continent. *See also* 1831 BIO; 1839 BIO.

Agostino Bassi [b. near Lodi, Lombardy (Italy), September 25, 1773, d. Lodi, February 8, 1856] reports that a disease of silkworms is contagious and

caused by a fungus, giving impetus to development of the germ theory of disease. *See also* 1865 BIO.

Johannes Purkinje notes that animal tissues are, like plant tissues, made from cells. *See also* 1665 BIO; 1838 BIO.

Communication

Joseph Henry develops the basic principles of the modern telegraph, put into more practical form 11 years later by Samuel Finley Breese Morse [b. Charlestown, Massachusetts, April 27, 1791, d. New York City, April 2, 1872], such as the electric relay and the use of Earth as a ground. The electrical relay enables a current to travel long distances from its origin. *See also* 1833 COMM; 1836 COMM.

During the summer William Fox Talbot begins to use his new invention of photography to take experimental pictures of his home at Lacock Abbey. *See also* 1834 COMM.

Earth science

Geologist Sir Roderick Impey Murchison [b. Tarradale, Scotland, February 19, 1792, d. London, October 22, 1871] identifies the Silurian period in Earth's history. Adam Sedgwick [b. Yorkshire, England, March 22, 1785, d. Cambridge, January 27, 1873] identifies the Cambrian period. *See also* 1834 EAR; 1838 EAR.

Energy

Michael Faraday, independently from Joseph Henry, rediscovers the principles of self-induction, or inductance, and publishes it. *See also* 1832 ENER.

Food & agriculture

Henry Burden begins to manufacture horseshoes by machinery, rather than making them by hand. *See also* 1825 TOOL.

Materials

William Gossage [b. Burgh-in-the-Marsh, England, 1799, d. 1877] invents a tower that absorbs hydrogen chloride, an important step in the development of the chemical industry. *See also* 1810 CHEM.

Physics

Gustave-Gaspard de Coriolis's *Mémoire sur les équations du mouvement relatif des systèmes de corps* ("notes on the equations of relative movement of systems of bodies") describes the Coriolis effect: the deflection of a moving body caused by Earth's rotation. The Coriolis effect explains the main directions of winds on Earth. *See also* 1735 EAR.

Tools

John Ireland Howe, using a greatly improved version of his 1832 pin-making machine, founds the Howe Manufacturing Company, a successful manufacturer of straight pins in an age when they are used not only for clothing, but also for most of the purposes for which paper clips are used today. *See also* 1832 TOOL.

Samuel Colt [b. Hartford, Connecticut, July 19, 1814, d. Hartford, January 10, 1862] patents his revolver with a rotating breech. The breech turns in such a way that each time the trigger is pulled, a new bullet is placed in front of the barrel. Colt's invention was inspired by his observation of a helmsman turning a

wheel that had a clutch that could lock it in several positions. *See also* 1812 TOOL.

James Nasmyth [b. Edinburgh, Scotland, August 19, 1808, d. London, May 7, 1890] develops the modification of a metal plane known as the shaper. *See also* 1817 TOOL; 1842 TOOL.

Joseph Whitworth [b. Stockport, England, December 21, 1803, d. Monte Carlo, Monaco, January 22, 1887] patents the faceplate lathe, which has a disk attached to the rotating shaft to hold flat or irregularly shaped work. *See also* 1800 TOOL; 1855 TOOL.

Transportation

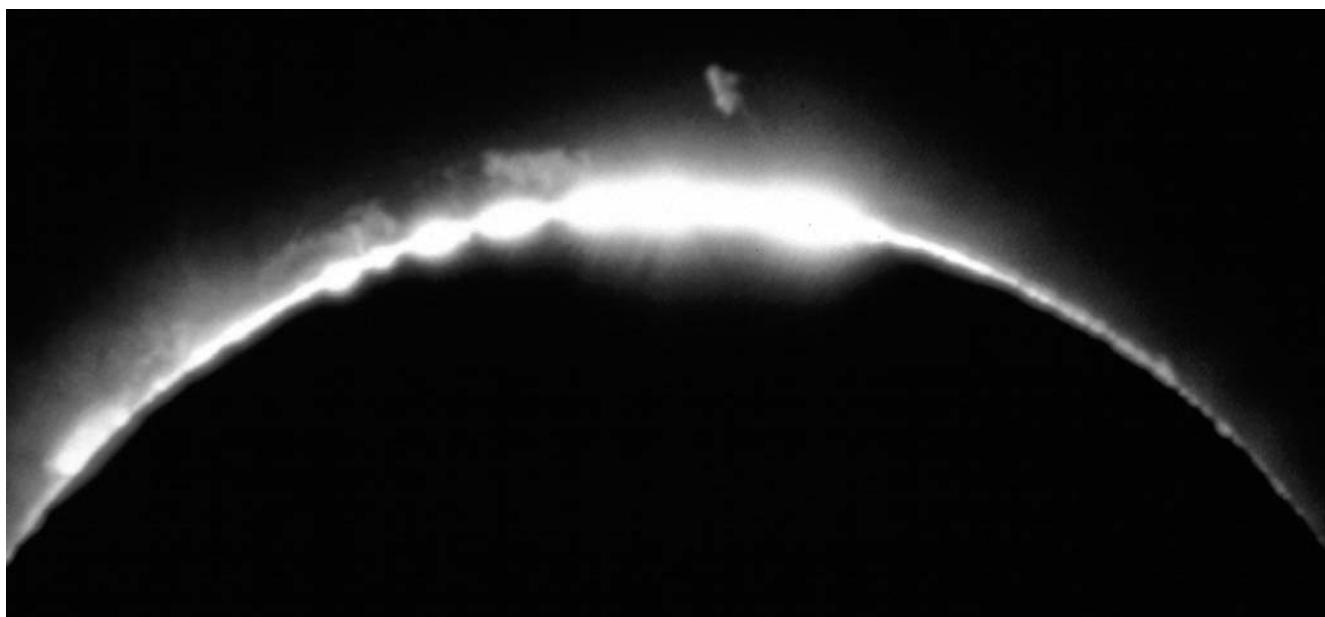
Legislation in England promoted by horse-coach drivers inhibits further development of steam carriages by imposing prohibitive tolls. *See also* 1831 TRAN.

1836

★ Astronomy

Francis Baily [b. Newbury, England, April 28, 1774, d. London, August 30, 1844] describes Baily's beads, the bright spots along the Moon's edge seen during a total eclipse (caused by sunlight peeping between mountains on the lunar horizon).

Wilhelm Beer [b. Berlin, January 9, 1797, d. Berlin, March 27, 1850] and Johann Heinrich Mädler [b. Berlin, May 29, 1794, d. Hanover, Germany, March 14, 1874] produce a map of the visible lunar surface. It remains the best for several decades. *See also* 1840 AST.



BAILY'S BEADS ON EDGE OF MOON DURING SOLAR ECLIPSE The glowing dots of various sizes along the rim of the Moon are sunlight streaming through the valleys of the Moon. The brighter region near the middle of the picture is caused by solar prominences that are just becoming visible as the Sun and Moon shift positions with respect to each other. As the edge of the solar disk reaches beyond the Moon, its bright gleam along with the glow around the edge of the Moon will form an image known as the diamond ring.



Asa Gray

[b. Sauquoit, New York, November 18, 1810, d. Cambridge, Massachusetts, January 30, 1888]

A noted plant collector, Harvard University professor, and author of a series of botany textbooks, Gray helped found the study of plant geography. He noted similarities in plants of eastern Asia and eastern North America, theorizing that the plants were descendants of a single species that had lived across the Northern Hemisphere prior to the Ice Age.

➤ Biology

Elements of Botany by Asa Gray is published.

The first living lungfish species, now viewed as an important link between fish and amphibians, is discovered.

Theodor Schwann discovers the substance in the stomach that aids digestion of egg white, the enzyme pepsin, the first known animal enzyme. He reports the discovery in *Über das Wesen des Verdauungsprozesses* ("on the essence of digestion"). See also 1833 BIO; 1871 BIO.

➤ Chemistry

Auguste Laurent demonstrates that a chlorine atom can be substituted for a hydrogen atom in a chemical with little change in properties. As this refutes the prevailing concept,

his work is rejected by the chemical community at first. Gradually, Laurent's ideas are accepted. See also 1835 CHEM.

Edmund Davy [b. 1785, d. 1857], a cousin of Sir Humphry Davy, discovers acetylene gas (then called ethyne), which he obtains from potassium carbide.

➤ Communication

Edward Davy [b. Ottery St. Mary, England, June 16, 1806, d. January 27, 1885], independently from Joseph Henry, rediscovers the electric relay and applies it to the telegraph. See also 1837 COMM.

➤ Energy

John Frederic Daniell invents the Daniell cell, the first reliable source of electric current, based on the interactions of



Theodor Schwann

[b. Neuss (Germany), December 7, 1810, d. Cologne, Germany, January 11, 1882]

In 1839 Schwann proposed that all organisms are composed of cells. Together with Matthias Schleiden he formulated the cell theory of life. Schwann also discovered the cells, now known as Schwann cells, that form a sheath surrounding nerve axons and conducted experiments that helped disprove the theory of spontaneous generation. He coined the word *metabolism* to define the chemical changes that take place in cells and he demonstrated that yeast organisms cause fermentation of sugar solutions.

copper and zinc. *See also* 1816 ENER; 1839 ENER.

William Staite develops an arc lamp in which the movement of the carbon rods is regulated by a clockwork mechanism. *See also* 1834 ENER.

II Food & agriculture

On June 28 Hiram Moore and John Hascall of Climax, Michigan, patent their version of a combined thresher and harvester, a device now called the combine. The prototype was built in 1834. *See also* 1831 FOOD; 1935 FOOD.

S Mathematics

Mikhail Vasilevich Ostrogradsky [b. Pashennaya (Ukraine), September 24, 1801, d. Poltava (Ukraine), January 1, 1862] rediscovers Green's theorem on the conversion of multiple integrals (which continued to be largely overlooked until it was discovered for the fourth time — Gauss had also discovered it — by Lord Kelvin in 1846). *See also* 1828 PHY.

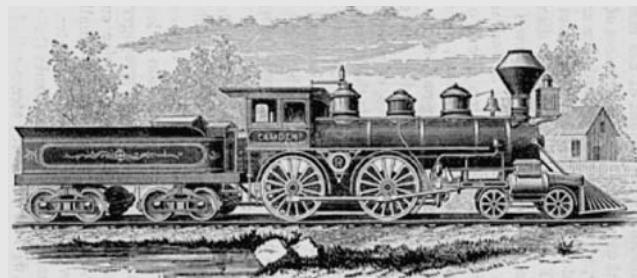
Joseph Liouville [b. St. Omer, France, March 24, 1809, d. Paris, September 8, 1882] founds *Journal de mathématiques pures et appliquées*. It becomes one of the most important mathematical journals in France. *See also* 1826 MATH.

I Tools

French mathematician Jean-Victor Poncelet publishes *Cours de mécanique appliquée aux machines* ("course in mechanics applied to machines"), which introduces the use of mathematics and physical principles in the design of machines. *See also* 1826 COMP.

United States railroads

The earliest railroads were in England. Although railroading on the English model gradually spread throughout Europe in the middle of the 19th century, the real advances in railroad travel came in the United States, where greater distances fostered a different philosophy. European engineers believed that locomotives could not pull heavy loads up hills. As early as 1836, however, Americans tried to prove that a locomotive could pull a train up a moderately steep hill, so American railroad lines traveled over high hills and even over mountains, using switchbacks along with cuts and tunnels when needed. Long American locomotives bounced on quickly laid rails and had to be equipped with cowcatchers because the unprotected lines ran through open country. Stout British locomotives traveled smoothly on short, level lines that were built to give a smooth ride because that was the only way British engineers thought the system would work. Fences were part of the plan. No cowcatchers for these protected railroad systems.



AMERICAN STEAM LOCOMOTIVE OF 19TH CENTURY Among the distinguishing features of the American design for a locomotive are the cab that protects the engineer and fireman as the train travels, the steam whistle and bell for announcing arrivals and for warning people or animals off the tracks, and the cowcatcher at the front of the train to prevent derailments from animals or other objects on the tracks.

The U.S. system, different as it is, started almost as soon as the first British railways proved the concept. Less than ten years after the first British common carrier, the state of Pennsylvania, worried about the opening of the Erie Canal in rival New York, started the Philadelphia and Columbia line. By the time the first railroad line opened in Greece, the coasts of the United States were linked by rail. America had become the railroad leader of the world in miles of track, freight hauled, number of operating locomotives, or any other measure.

→ Transportation

John Stevens of Great Britain patents a screw propeller. The same year John Ericsson of

Sweden patents a screw propeller for driving ships in Great Britain, eventually getting one-fifth of the 20,000

pounds offered for improvements in steamship propulsion by the British Admiralty. *See also* 1797 TRAN; 1839 TRAN.

1837

▲ Archaeology

Henry Creswicke Rawlinson, after heroic labors to read the "Mountain of the Gods" inscription of Darius the Great — hundreds of feet above the ground — manages to translate two paragraphs of Persian cuneiform text, 35 years after the obscure Georg Grotefend had accomplished a similar feat. *See also* 1802 ARCH; 1846 ARCH.

★ Astronomy

Johann Franz Encke discovers the small gap in Saturn's outer ring. It is later named after him. *See also* 1675 AST; 1866 AST.

Mensura Micrometricae ("micrometric measurement") by Friedrich Georg Wilhelm von Struve [b. Alton (Germany), April 15, 1793, d. Pulkovo, Russia, November 23, 1864] is the first good catalog of double stars. *See also* 1802 AST; 1892 AST.

↗ Biology

Henri Dutrochet shows that only those parts of plants that contain chlorophyll absorb carbon dioxide and that they do so only in the presence of light. *See also* 1817 BIO; 1865 BIO.

Theodor Schwann shows that yeast is made of small living organisms, but he is not believed by biologists or chemists, who are finally convinced by the work of Louis Pasteur in 1856 and subsequent years. Schwann also

demonstrates that yeast can cause fermentation. *See also* 1680 BIO; 1856 BIO.

Communication

Painter Samuel F.B. Morse patents his version of the telegraph, a machine that sends letters in codes made up of dots and dashes. The idea of using an electromagnet for transmitting signals came upon him during a transatlantic trip during which he met a scientist who demonstrated such a device. The idea to use dots and dashes to represent letters, the "Morse code" that will make single-line telegraphy practical, comes from his collaborator, American engineer Alfred

Vail. *See also* 1809 COMM; 1844 COMM.

Carl August Steinheil [b. Rappersweiler (Germany), 1801, d. Monaco, 1870] invents a telegraph system in which characters are printed on a paper ribbon. He is the first to use an induction machine as a current source. He also rediscovers that Earth can serve as a conductor, thus allowing a telegraph system linked by only one wire. The return wire is replaced by Earth itself. The system, however, is not commercially exploited. *See also* 1835 COMM.

Charles Wheatstone and William Fothergill Cooke [b. Ealing, England, May 4, 1806, d. Surrey, June 25, 1879]

patent the first English telegraph, the "five-needle telegraph," a machine with five pointers that point to letters of the alphabet. They found the Electric Telegraph Company. Their telegraph links Liverpool with Manchester. *See also* 1839 COMM.

Earth science

Louis Agassiz begins to use the term *die Eiszeit* (Ice Age) to describe his view that the whole of Europe had been covered with glaciers in the past. *See also* 1821 EAR; 1840 EAR.

Energy

The Parliament in London begins to use an air-condi-

tioning system devised by Jacob Perkins. *See also* 1831 ENER.

Food & agriculture

John Deere [b. Rutland, Vermont, February 7, 1804, d. Moline, Illinois, May 17, 1886] of Grand Detour, Illinois, begins making plows of saw-blade steel. They become the first popular horse-drawn plows. The company he founds remains one of the leading makers of farm equipment to this day. *See also* 1833 FOOD; 1881 FOOD.

Materials

Moritz Hermann von Jacobi [b. Potsdam (Germany), September 21, 1801, d. St. Peters-

Intellectual and technological property

A patent is a capitalist device that like many great ideas works on a paradoxical principle: The way to spread the benefits of an invention is to restrict the number of people who can exploit it.

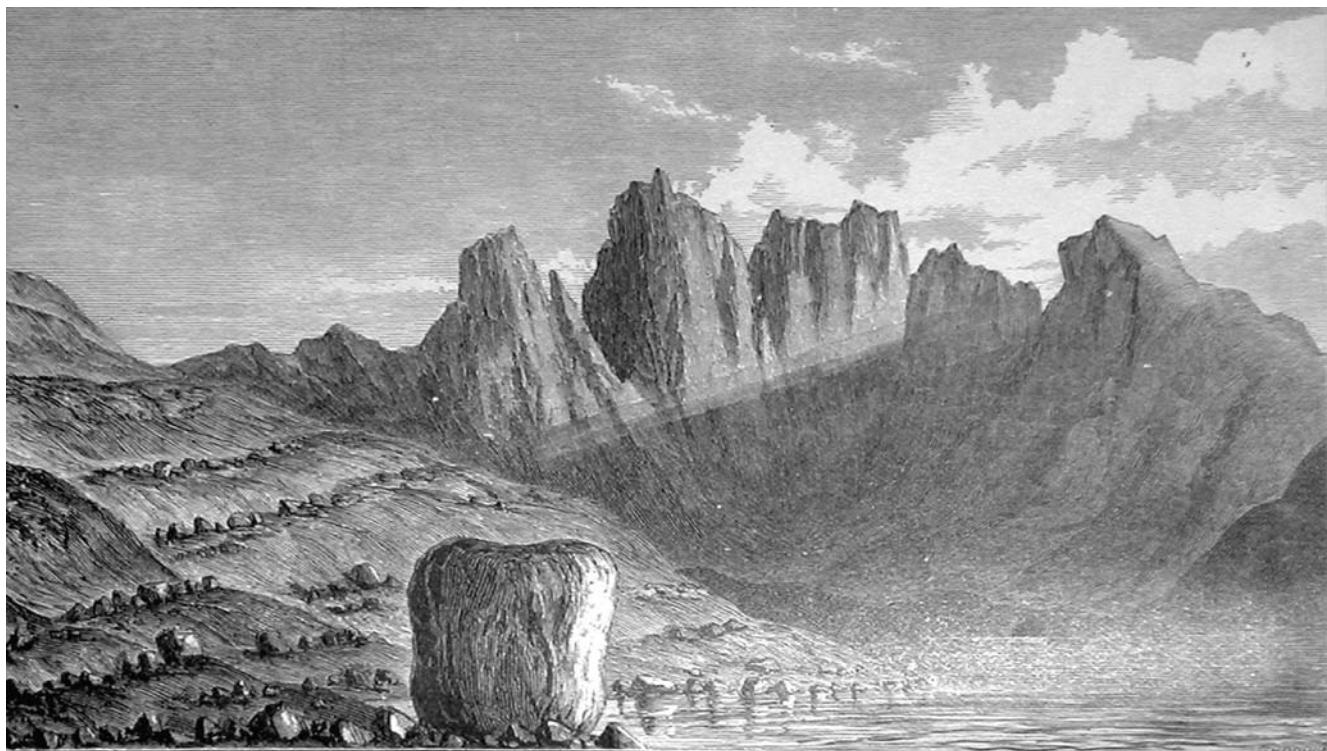
Other forms of intellectual property are protected in different ways. A scientific discovery, which is intended to be shared by everyone, is covered by informal agreement in the scientific community granting "ownership" with priority. No legal rights are deemed possible. A trademark or trade name can be registered and protected, but that is solely for the protection of the owner. Copyright is closer in concept to patent, but is much more concerned with protecting structure and substance of thought than it is with providing a monopoly on an idea or a structure. Indeed, ideas are not copyrightable; only their expression and arrangement can be copyrighted. Ideas for inventions, however, are the basis of monopoly; and monopoly is the original purpose of the patent.

Capitalism and the middle class were babies of the Renaissance, but they did not become adult ideas until the Industrial Revolution. Patents have the same history, starting in Italy in the 15th and 16th centuries. Queen Elizabeth I may have been the first British monarch to issue monopolies, which included but were not limited to patents. By the time of James I, the business of royal monopolies had gotten out of hand, and a succession of efforts to control monopolies, which treated inventions different-

ly from other monopolies, had the somewhat inadvertent effect of creating the first English Patent Law, although it was not codified as such until late in the 19th century, after the example of the Patent Law in the United States.

By the time the U.S. Constitution was being written, the Founding Fathers had a good philosophical grasp of intellectual property, and provisions regarding it were included: Article I, Section 8 gave Congress the power "To promote the progress of Science and Useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries." Almost as soon as the Constitution was ratified, Congress proceeded to set up a patent law to protect monopolies on inventions. By 1836 the U.S. Patent Office was functioning effectively, and it soon became apparent that invention fared better under the U.S. system than under any other. A monopoly for a limited time on a specific invention encouraged people to invent, knowing they could be protected, and enabled them to sell rights to others who had the capital or existing trade to manufacture and promote an invention.

In 1883 Great Britain consolidated its patent laws along U.S. lines and the International Convention in Paris worked out a way to handle patents in its many signatory nations. The European Patent Organization of 1953 was among several agreements that were precursors to the European Community. Today there are effective ways for an inventor to file a patent once in one country and, with suitable payments and searches, have it accepted in nations around the world.



EVIDENCE OF THE GREAT ICE AGE The engraving from Gieke's *The Great Ice Age* shows a formerly glaciated valley on the isle of Skye off the coast of Scotland. Not only are there rocks aligned by the passage of the glacier and one large erratic rock in the foreground, but the mountains themselves appear to have been sculpted by the now departed glacier. Evidence of this nature convinces Agassiz and others that all Europe had once been covered by ice.

burg, Russia, March 10, 1874] introduces electroplating, first developing silver plating in Russia, and then electroplating with nickel and chrome. *See also* 230 BCE TOOL.

S Mathematics

Pierre Wantzel [b. Paris, June 5, 1814, d. Paris, May 21, 1848] proves that it is impossible to trisect an arbitrary angle with compass and straightedge, resolving one of the three classic problems of Antiquity. *See also* 420 BCE MATH; 1882 MATH.

Matthias Jakob Schleiden

[b. Hamburg (Germany), April 5, 1804, d. Frankfurt, June 23, 1881]

In 1838 Schleiden proposed that all plants are composed of cells; together with his friend Theodor Schwann he formulated the cell theory of life. Schleiden observed various cell structures and activities such as protoplasmic streaming. Schleiden also found that certain fungi live on or within the roots of some plants. This relationship between fungi and plants, called mycorrhiza ("fungi roots"), has since been shown to be very common and extremely beneficial to both organisms.



1838

★ Astronomy

Friedrich Bessel is the first to determine how far away a star (other than the Sun) is by measuring the parallax of 61 Cygni, now thought to be 11.4 light-years away. Bessel had calculated the distance as

657,000 astronomical units, or 10.4 light-years.

Johann Gottfried Galle [b. Pabsthaus, Saxony, June 9, 1812, d. Potsdam, Prussia, July 10, 1910] discovers a ring of Saturn inside the B ring, now called the Crêpe ring or C ring. *See also* 1850 AST.

Biology

Matthias Schleiden recognizes that cells are the fundamental components of plants. *See also* 1665 BIO; 1839 BIO.

On July 10, Jöns Jacob Berzelius proposes in a letter to Gerardus Johannes Mulder [b. Netherlands, 1802, d. 1880] the name *protein* ("in the front position")

to describe the main ingredient in egg albumin. Mulder accepts the name and in an article published on July 30 applies it to the class of organic compounds that includes albumin. Mulder also describes his systematic studies of albumin and related compounds, pointing out that all proteins contain carbon, hydrogen, nitrogen, and oxygen. *See also* 1875 BIO.

Communication

Charles Wheatstone invents the stereoscope. He also seems to be the first to recognize that distance perception is produced by seeing with two eyes. The stereoscope will later be improved by David Brewster. *See also* 1829 COMM; 1847 COMM.

Earth science

Sir Roderick Impey Murchison's *The Silurian System* details the geological history of the strata underlying the Old Red Sandstone, which is a large stratum of weathered Devonian rock in Scotland, Wales, and England that contains many fossils, especially of freshwater fishes. *See also* 1835 EAR; 1879 EAR.

Energy

Charles G. Page [b. Salem, Massachusetts, January 25, 1812, d. Washington, DC, May 5, 1868] is the first to build an electric generator with an electrically excited field magnet made from soft iron instead of a permanent magnet, such as those used by Faraday and Pixii. *See also* 1832 ENER; 1845 ENER.

Food & agriculture

Agricultural chemist Jean-Baptiste Joseph Dieudonné Boussingault [b. Paris, February 2, 1802, d. Paris, May 12,

1887] discovers nitrogen fixation in plants, the main reason that crop rotation is useful. His experiments began in 1834. *See also* 1804 FOOD; 1841 FOOD.

Materials

Théophile-Jules Pelouze [b. Valognes, France, February 26, 1807, d. Paris, May 31, 1867] develops nitrated paper as an explosive, a precursor of nitrocellulose. *See also* 1833 MATR; 1846 MATR.

Charles Frederick Kuhlmann [b. Colmar, France, May 22, 1803, d. Lille, France, January 27, 1881] introduces a new method for preparing nitric acid by the oxidation of ammonia in the presence of platinum as a catalyst. *See also* 1774 CHEM; 1858 MATR.

Mathematics

In an encyclopedia article on mathematical induction, English mathematician August De Morgan [b. Madras, India, June 27, 1806, d. London, March 18, 1871] makes the first known use of that name for the method of proof, despite the fact that De Morgan proposes earlier in the article that the method should be called "successive induction." *See also* 1666 MATH.

Medicine & health

Italian chemist Raffaele Piria, working at the Sorbonne, is the first to isolate salicylic acid, which he obtains from willow bark. This is an important precursor of aspirin. *See also* 1859 CHEM.

William Beaumont's *Experiments and Observations on the Gastric Juice and the Physiology of Digestion* relates his study started in 1822 of digestion in vivo and in vitro with a

wounded man whose stomach remains partially open through a healed hole in the abdomen. *See also* 1822 MED.

Johannes Müller [b. (Germany), 1801, d. 1858] presents his Law of Specific Nerve Energies, saying that the perception of sensation depends on the kind of sense organ stimulated rather than on the nature of the stimulus. *See also* 1833 MED; 1842 MED.

Physics

Michael Faraday rediscovers the phosphorescent glow produced by electric discharges in gases at low pressure. He also discovers the Faraday dark space, an unlit region in a partially evacuated tube with a current passing through the gas that is found between the glow and the cathode. As gas pressure is lowered, the Faraday dark space moves away from the cathode and the glow is on both sides of it (the glow nearest the cathode is called the positive column). At still lower pressures, the dark space grows and displaces the glow completely. *See also* 1709 ENER; 1857 PHY.

Transportation

The steamship *Sirius* is the first to cross the Atlantic Ocean on steam power alone, taking 18 days and very nearly running out of coal before reaching New York from London, despite carrying 450 tons at the start. The trip proves false the belief that a ship could not carry enough coal for such a long voyage. Three other steamships also make the crossing during the year.

In 1837 Isambard Brunel had built the *Great Western*, which in 1838 becomes the first ship to cross the Atlantic regularly on steam power.

Joseph Francis, inventor of the "unsinkable" lifeboat, patents a more practical design based on wood that uses a cable that attaches to shore when the lifeboat is used to aid a sinking vessel. *See also* 1819 TRAN; 1845 TRAN.

1839

Archaeology

John Lloyd Stephens [b. Shrewsbury, New Jersey, November 28, 1805, d. New York, October 13, 1852] and artist Frederick Catherwood [b. 1799, d. September 20, 1854] embark on an expedition to Central America with the goal of locating the ruins of Copán and investigating them. After buying Copán they discover that it is the remains of a civilization largely unknown to Europeans, which we now recognize as the Maya. *See also* 1841 ARCH.

Astronomy

Thomas Henderson [b. Dundee, Scotland, December 28, 1798, d. Edinburgh, Scotland, November 23, 1844] measures the parallax of alpha-Centauri, the second star other than the Sun whose distance from Earth is found. Henderson had the measurements as early as 1832, but failed to interpret them correctly until after Friedrich Bessel's determination of the distance to a star in 1838. *See also* 1838 AST.

Harvard College Observatory is founded, the first official observatory in the United States, with William Cranch Bond [b. Portland, Maine, September 9, 1789, d. Cambridge, Massachusetts, January 29, 1859] as its first direc-

tor. A 38-cm (15-in.) refractor will be installed there in 1847, equal at the time to one other as the largest in the world. In Russia, Pulkova Observatory is founded; Friedrich von Struve becomes the first director. *See also* 1675 AST.

Biology

Johannes Purkinje coins the word *protoplasm* ("earliest cell material") for the basic substance of life. The term is later adopted to mean the main contents of a cell. *See also* 1846 BIO.

Theodor Schwann's *Mikroskopische Untersuchungen über die Übereinstimmung in dem Struktur und dem Wachstum der Tiere und Pflanzen* ("microscope-based studies of the similarity in structure and growth of animals and plants") discusses the existence of cells in animals and lays the foundation of cell biology.

See also 1828 BIO.

Darwin's *Journal of Researches into the Geology and Natural History of the Various Countries Visited by HMS Beagle*

1832–36 is an account of Darwin's work as a scientist, principally in South America, where he finds fossils, collects plants and animals, and studies the geology of the continent.

See also 1835 BIO; 1840 BIO.

Chemistry

Carl Mosander discovers the chemical element lanthanum (La).

Communication

On January 31 William Fox Talbot describes his invention of photography to the Royal Society. In September Fox Talbot, after an accidental discovery of the process, develops the first form of photographic



AN EARLY PHOTOGRAPH BY FOX TALBOT The very earliest of the pictures Fox Talbot took of Lacock Abbey and of the people who lived or worked there are fuzzy and dim, but after the calotype process was invented and hypo was introduced for keeping images from dimming, Fox Talbot was able to produce images such as this 1844 picnic party at Lacock Abbey.

negatives, which are called calotypes. The process consists of taking photographs on paper made sensitive to light by silver iodide. He will patent the process on February 8, 1841. *See also* 1835 COMM; 1851 COMM.

John Herschel demonstrates that the method used by William Fox Talbot for slowing down the darkening of silver salts exposed to light could be greatly improved by substituting sodium thiosulphate (universally known as "hypo," short for sodium hyposulphite, an older name for the compound) for the sodium chloride (table salt) used by Fox Talbot.



AN EARLY DAGUERREOTYPE An alternative photographic process, the daguerreotype, initially competed with Fox Talbot's system. Although daguerreotype exposure times were long and the surface very fragile, needing to be protected with glass, the process was popular in the 1840s and 1850s, especially for portraits, which were thought more lifelike than the first photographs.

Louis-Jacques Daguerre [b. Seine-et-Oise, France, November 18, 1789, d. Paris, July 12, 1851] announces in Paris on August 19 his process for making photographs (a silver image on a copper plate), known as daguerreotypes. *See also* 1822 COMM; 1851 COMM.

A commercial telegraph system starts operation in Great Britain; by 1850 the network extends over 5600 km (3500 mi). *See also* 1837 COMM.

Earth science

Charles Lyell identifies the Pleistocene period in Earth's history. *See also* 1835 EAR; 1841 EAR.

Sir Roderick Impey Murchison's and Adam Sedgwick's *On the Physical Structure of Devonshire* is an important study of the rocks of the Devonian era.

A Treatise on Crystallography by William Hallowes Miller [b. Llandovery, Wales, April 6, 1801, d. Cambridge, England, May 20, 1880] introduces the Millerian indices for crystals, a coordinate system that uses three numbers to describe each type of crystal face, a system still in use. *See also* 1819 CHEM; 1844 CHEM.

Energy

William Robert Grove [b. Swansea, Wales, July 11, 1811, d. London, August 1, 1896] develops the first fuel cell, a device that produces electrical energy by combining hydrogen and oxygen. Although theoretically an excellent way to produce electricity, fuel cells have failed to become practical for most applications. *See also* 1800 ENER; 1959 ENER.

William Robert Grove develops a form of electric cell

based on zinc and platinum electrodes in two forms of acid separated by a diaphragm. This cell has nearly double the voltage of the Daniell cell. *See also* 1836 ENER; 1859 ENER.

Alexandre-Edmond Becquerel [b. Paris, March 24, 1820, d. Paris, May 11, 1891] discovers the photovoltaic effect, the first of several photoelectric effects discovered in the 19th century. He observes a voltage between two electrodes in an electrolyte produced by exposing one electrode to light. *See also* 1954 ENER.

Food & agriculture

Thomas Kensett and William Underwood switch their canning factories in the United States from the use of jars to the use of metal containers. *See also* 1819 FOOD.

Materials

Charles Goodyear [b. New Haven, Connecticut, December 29, 1800, d. New York, July 1, 1860] discovers vulcanization of rubber (the addition of sulfur to rubber and the processing of the combination to make it stable during both heat and cold) by "accident." Goodyear had been seeking such a process for about ten years when he spilled some of a sulfur-rubber mixture on a hot stove — the cooled rubber was the stable form he sought. Sulfur produces cross-links between rubber polymers. *See also* 1823 MATR. 1845 MATR.

Isaac Babbitt [b. Taunton, Massachusetts, July 26, 1799, d. Somerville, Massachusetts, May 26, 1862] invents an antifriction alloy (called Babbitt metal) that becomes extensively used in bearings.

Mathematics

Gauss lays the foundations of potential theory, which becomes an independent mathematical theory that considers the properties of functions that behave like the potential forces of gravity, electromagnetism, or hydrodynamics (but without any physical assumptions).

Gabriel Lamé [b. Tours, France, July 22, 1795, d. Paris, May 1, 1870] proves that Fermat's "last theorem" is true for $n = 7$, bringing the known proved cases to $n = 3, 4, 5$, and 7. *See also* 1825 MATH; 1847 MATH.

Tools

James Nasmyth makes a drawing of a steam hammer on November 24, a design developed at the request of Isambard Brunel, who needed a device to forge the paddle wheel shaft of his large steamships. The steam hammer is an extremely powerful tool for working iron, but can be adjusted to light taps of the kind used in breaking an egg. *See also* 1842 TOOL.

Transportation

Blacksmith Kirkpatrick MacMillan [b. Kier, Scotland, 1813, d. January 26, 1878] develops a bicycle powered by treadles and driving rods. The first bicycle that does not require the rider's feet to touch the ground, it is called a velocipede. *See also* 1818 TRAN; 1861 TRAN.

On an order from the U.S. navy, John Ericsson outfits a British iron steamship with his screw propeller. The ship reaches New York in May and Ericsson himself soon follows. The remainder of his ship-

building career takes place in the United States. *See also* 1836 TRAN; 1844 TRAN.

1840

Astronomy

John William Draper [b. Saint Helens, England, May 5, 1811, d. Hastings-on-Hudson, New York, January 4, 1882] becomes the first to take daguerreotypes of the Moon (perhaps in 1839). *See also* 1850 AST.

Biology

Darwin's *Zoology of the Voyage of the Beagle* describes the animals collected during his work on a scientific expedition. *See also* 1839 BIO; 1842 EAR.

Chemistry

Swiss-Russian chemist Germain Henri Hess [b. Geneva, Switzerland, August 8, 1802, d. St. Petersburg, Russia, December 13, 1876] announces the law that will be named after him (Hess's law): The amount of heat released or absorbed in a chemical change depends only on the initial and final states, not on the reactions involved.

German-Swiss chemist Christian Schönbein [b. Württemberg (Germany), October 18, 1799, d. Sauersberg, Germany, August 29, 1868] discovers ozone (from the Greek for "smell") by its strong odor around electrical equipment. *See also* 1974 ECOL.

Jean-Baptiste-André Dumas' theory of structural types advances the idea that the properties of organic compounds result from the structure of their molecules more than from the elements that

make up the molecules. *See also* 1834 CHEM.

Communication

John Benjamin Dancer [b. London, October 8, 1812, d. November 24, 1887] develops a method for making photographs of microscopic objects with magnifications of up to 20 times. He exhibits a photomicrograph of a flea in Liverpool. *See also* 1839 COMM.

James Haddon Young and Adrien Delcambre of Lisle, France, develop the first practical typesetting machine, using a design by Henry Bessemer.

Scottish clockmaker Alexander Bain [b. Watten, Scotland, October 1810, d. Kirkintilloch, Scotland, January 2, 1877] proposes a picture transmitter and receiver based on a pendulum apparatus. A metal version of the image to be sent is scanned by a pendulum, which sends an electrical impulse over a wire when the pendulum is near the metal and none when it is not. At the receiving end, a matching pendulum transmits the electrical impulses to treated paper that changes color in response to an electric current. The entire mechanism at each end is controlled by clockwork. Although patented in 1843, Bain's proposal will never be developed as a practical device. *See also* 1863 COMM.

Optician Josef Max Petzval [b. Spisska Bela, Czechoslovakia, January 6, 1807, d. Vienna, Austria, September 17, 1891] designs an improved camera lens for portraits, based on extensive calculations that had been performed by ten military calculators over several years. The lens is produced by

the Viennese optician Voigtlaender. In 1856, Petzval also designs a lens for landscapes.

Prepaid postage is introduced in England with the "penny black" stamp. Previously, the recipient had paid for receipt of mail. Furthermore, the earlier system involved high charges for each sheet of paper. The new postage stamp system has low charges based on the weight of the message. *See also* 1830 COMM.

Earth science

Louis Agassiz's *Etudes sur les glaciers* ("studies of glaciers") describes motions and deposits of glaciers that confirm his theories on the Ice Ages. *See also* 1837 EAR; 1856 EAR.

James Hall [b. Hingham, Massachusetts, September 12, 1811, d. 1898] discovers a fossil in New York State that he names *Sauripterus*. Although a fish, it is the first fossil found that has the same basic pattern in its limbs as amphibians and other tetrapods.

Energy

William Robert Grove succeeds in lighting an auditorium with impractical and very expensive incandescent lamps that use platinum coils in inverted glasses sealed with water. *See also* 1820 ENER; 1841 ENER.

Materials

Friedrich Gottlob Keller [b. 1816, d. 1895], either upon observing children playing with a paste of sawdust and water or upon learning that wasps make paper from chewed up wood (perhaps both), develops a method of

preparing paper from ground wood. *See also* 1798 MATR.

Medicine & health

Pathologischen Untersuchungen ("pathological investigations") by Friedrich Gustav Jakob Henle, German pathologist and anatomist [b. Fürth (Germany), July 19, 1809, d. Göttingen, Germany, May 13, 1885] expresses his conviction that diseases are transmitted by living organisms, although he offers no hard evidence. *See also* 1876 MED.

Physics

James Prescott Joule [b. Salford, Lancashire, England, December 24, 1818, d. Sale, England, October 11, 1889] discovers the relationship between electric current, resistance, and the amount of heat produced. *See also* 1821 PHY; 1843 PHY.

Tools

Italian physicist Giovanni Battista Amici [b. Modena (Italy), March 23, 1786, d. Florence, Italy, April 10, 1868] invents the oil-immersion microscope, one of his innovations in microscope building that results in instruments with an enlarging power of 6000 times. *See also* 1792 TOOL.

Alexander Bain develops a clock driven by electricity. *See also* 1829 TOOL.

Transportation

The first railroad dining cars make their appearance in the United States. *See also* 1832 TRAN; 1868 TRAN.

British locomotive designer Daniel Gooch [b. Bedlington, Northumberland, England, August 24, 1816, d. October 15, 1889] builds the Firefly,

the most powerful locomotive of its time, reaching average speeds of 80 km/h (50 mi/h). *See also* 1830 TRAN; 1846 TRAN.

1841

Archaeology

John Lloyd Stephens's *Incidents of Travel in Central America, Chiapas, and Yucatán*, illustrated by Frederick Catherwood, reports on his discoveries of the Maya civilization at Copán, Palenque, and Uxmal. The book is immensely popular and introduces the Maya to the United States and Europe. *See also* 1839 ARCH; 1848 ARCH.

Astronomy

Friedrich Bessel interprets measurements dating from 1834 to show that the star Sirius has an unseen companion. Later this companion, Sirius B, will be the first white dwarf to be observed directly. *See also* 1862 AST.

Biology

Anatomist Rudolf Albert von Kölliker [b. Zürich, Switzerland, July 6, 1817, d. Würzburg, Bavaria, November 2, 1905] establishes that sperm are actual cells that have formed by differentiation from cells in the testes. *See also* 1779 BIO; 1872 BIO.

Chemistry

Jöns Jakob Berzelius observes chemical allotropy (two different forms of the same element) by converting charcoal into graphite. *See also* 1844 CHEM.

Construction

Joseph Stephenson introduces the use of the steam hammer

for driving piles into the ground (the pile driver), an important application in bridge construction. *See also* 1839 TOOL.

Joseph Paxton completes the Great Stove, a greenhouse (conservatory) at Chatsworth, England, that is broader than any of the glass-topped railroad stations of the time. This conservatory uses an arched ridge-and-furrow roof. *See also* 1832 CONS; 1849 CONS.

William Marshall builds a state-of-the-art flax mill at Leeds (England) in which the main factory floor covers more than 8000 m² (86,000 sq ft). Rows of conical skylights provide natural lighting through the mill, while between the skylights sheep graze on the roof, which is covered with turf for insulation. The pillars that support the roof are pipes that conduct rainwater to the basement. Steam engines in the basement not only power the machinery, but also provide the steam to heat the building and the hot water for baths for the employees. *See also* 1771 TOOL.

Earth science

Arnold Escher von der Linth [b. Zurich, Switzerland, June 8, 1807, d. July 12, 1872] describes structures in the Alps where tens of kilometers of rock layers have been folded and laid over other layers “like a napkin”—nappes, as geologist came to call such giant folds.

Roderick Impey Murchison identifies the Permian period in Earth’s history. *See also* 1839 EAR; 1854 EAR.

Geologist Clarence Edward Dutton [b. Wallingford, Con-

necticut, May 15, 1841, d. Englewood, New Jersey, January 4, 1912] conducts a study of volcanoes and earthquakes that leads him to the correct conclusion that the continents are made from lighter rock than the oceans. He proposes the name *isostasy*, still used, to describe how a lightweight mountain floats in heavier rock.

Friedrich Bessel determines the exact shape of Earth, based on measurements of parts of meridians of longitude in East Prussia, Germany that he had supervised ten years earlier. He determines that Earth departs from a perfect sphere, which has an ellipticity of zero, having instead an ellipticity of 1/299. *See also* 1792 EAR.

Energy

Frederick de Moleyns obtains the first patent for an incandescent lamp, an evacuated glass containing powdered charcoal that bridges a gap between two platinum filaments. *See also* 1840 ENER; 1845 ENER.

Food & agriculture

Jean-Baptiste Boussingault shows that the amount of carbon, hydrogen, oxygen, and nitrogen in plants is larger than the amounts supplied by manure. *See also* 1838 FOOD.

Materials

The first beehive oven for making coke to be built in the United States starts operating in Pennsylvania. *See also* 1620 MATR; 1850 MATR.

John Augustus Roebling [b. Mulhausen, Prussia, June 12, 1806, d. Brooklyn, New York, July 22, 1869] manufactures

the first wire-rope cable in the United States, a project that eventually brings him and his family into the business of building suspension bridges, although they also manufacture the cables for many suspension bridges built by others. *See also* 1845 CONS.

Mathematics

Lambert-Adolphe Quetelet establishes a central statistical bureau in Belgium that is widely imitated around the world. *See also* 1831 MATH.

Augustin Cauchy states an early version of what will be known as the Nyquist sampling theorem, an important result describing how many and what kind of samples are needed to reconstruct a curve. The theorem will be formulated more completely in 1928 and become one of the cornerstones of information theory. *See also* 1928 COMM.

Medicine & health

Charles Thomas Jackson [b. Plymouth, Massachusetts, June 21, 1805, d. Somerville, Massachusetts, August 28, 1880] discovers that ether is an anesthetic. *See also* 1842 MED.

Surgeon James Braid [b. Rylawhouse, Scotland, 1795, d. Manchester, England, March 25, 1860] renames mesmerism *hypnotism* and gives the practice some medical respectability by correctly explaining why it works. *See also* 1774 MED; 1847 MED.

Tools

Painter John Goffe Rand [b. Bedford, New York, 1801, d. Roslyn, New York, January 21, 1873] patents the first squeezable tube, a device he has

developed for keeping oil paints from becoming gummy when painting outdoors. *See also* 1892 TOOL.

Joseph Whitworth introduces the standard screw thread in a paper presented to the Institution of Civil Engineers called *A Uniform System of Screw-Threads*. *See also* 1800 TOOL; 1864 TOOL.

Transportation

James Buchanan Eads [b. Lawrenceburg, Indiana, May 23, 1820, d. Nassau, Bahamas, March 8, 1887] patents a new type of diving bell and uses it for extensive salvage operations in the Mississippi River. *See also* 1756 TRAN.

1842

Anthropology

Swedish anatomist Anders Adolf Retzius [b. Stockholm, Sweden, October 13, 1796, d. Stockholm, April 18, 1860] introduces his theory on the use of head shapes, including the cranial index, to differentiate races (such as the Nordic, Mediterranean, and Alpine “races”). *See also* 1819 ANTH.

Archaeology

Karl Richard Lepsius [b. (Germany) 1810, d. 1844] begins a four-year expedition to Egypt. He will bring 60 barge loads of material, containing about 15,000 Egyptian antiquities, to Berlin from Egypt at the end of the tour. *See also* 1822 ARCH; 1849 ARCH.

Astronomy

On July 8 a total solar eclipse is observed by European astronomers. From it, Francis Baily infers that the corona and prominences are solar

rather than lunar — previously, it had been an open question. Dominique François Arago suggests correctly that the Sun consists of gas. Austrian astronomer G. A. Majocchi in Milan makes the first attempt to photograph totality, but misses. *See also* 1860 AST.

Biology

Darwin writes a 35-page abstract of his theory of the evolution of species, known as the “pencil sketch” from the method of composition. *See also* 1844 BIO.

Johann Japetus Steenstrup [b. Denmark, 1813, d. 1897] describes alternation of sexual and asexual generations in both plants and animals. *See also* 1851 BIO.

Chemistry

Eugène-Melchior Péligot [b. February 24, 1811] discovers uranium (U).

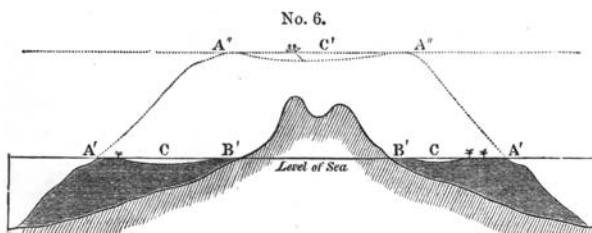
Construction

Charles Ellet, Jr. [b. Penn's Manor, Pennsylvania, January 1, 1810, d. Cairo, Illinois, June 21, 1862] builds the first important U.S. suspension bridge over the Schuylkill River near Philadelphia. *See also* 1825 CONS; 1848 CONS.

Earth science

English zoologist Richard Owen [b. Lancaster, England, July 20, 1804, d. Richmond Park, London, December 18, 1892] coins the name *dinosaur* to describe what we now recognize as two unusual groups of reptiles that were the dominant animals for about 175,000,000 years. *See also* 1822 EAR; 1858 EAR.

Darwin's *The Structure and*



A'A'—Outer edges of the barrier-reef at the level of the sea. The cocoanut trees represent coral-islets formed on the reef.

CC—The lagoon-channel.

B'B'—The shores of the island, generally formed of low alluvial land and of coral detritus from the lagoon-channel.

A''A'''—The outer edges of the reef, now forming an atoll.

C'—The lagoon of the newly-formed atoll. According to the scale the depth of the lagoon and of the lagoon-channel is exaggerated.

CHARLES DARWIN'S THEORY OF ATOLL FORMATION Atolls are circular rings of coral in the deep ocean. When first discovered, no one could explain how they form since corals cannot grow in deep water. Darwin recognized that atolls are the end of a process that starts with a volcanic mountain rising from the depths. Coral fringing reefs (labeled A') form in the shallow water near the mountain. The mountain gradually sinks back into the ocean, but the reefs continue to grow. The dotted line at the top shows sea level after the mountain has sunk and the atoll remains (labeled A''').

Distribution of Coral Reefs, being the first part of the geology of the voyage of the *Beagle*, classifies coral reefs into three types and presents Darwin's theory of the formation of atolls by subsidence of islands. *See also* 1840 BIO; 1844 EAR.

Energy

(Julius) Robert Mayer [b. Heilbronn, Württemberg (Germany), November 25, 1814, d. Heilbronn, March 20, 1878] is the first to state the law of conservation of energy, noting specifically that heat and mechanical energy are two aspects of the same thing. This is often called the first law of thermodynamics. *See also* 1824 ENER; 1847 PHY.

Food & agriculture

Samuel Dana describes how phosphates play a role in manure as fertilizer. Agriculturalist Sir John Bennett Lawes [b. Rothamsted, Eng-

land, December 28, 1814, knighted 1882, d. Rothamsted, August 31, 1900] patents superphosphate, an artificial fertilizer made from phosphate rock. In 1843, with aid from a student of chemist Justus von Liebig, he begins manufacturing superphosphate, which remains in common use today. *See also* 1820 FOOD.

The brothers M.A. and I.M. Cravath of Bloomington, Illinois, invent the disk plow. *See also* 1837 FOOD.

Materials

Ernst Werner von Siemens [b. Lenthe, Hanover, Germany, December 13, 1816, d. Berlin, December 6, 1892] invents and patents an electroplating process. *See also* 1837 MATR.

Mathematics

Ludwig Otto Hesse [b. Königsberg, (Kaliningrad, Russia), April 22, 1811, d.

Munich, Germany, August 4, 1874] publishes a paper on cubic and quadratic curves that introduces the Hessian determinant, a function that is useful in determining maximum, minimum, and turning points for surfaces (similar to the use of the second derivative in calculus of one variable for finding such points for curves).

Medicine & health

The first use of ether in surgery is by Crawford Williamson Long [b. Danielsville, Georgia, November 1, 1815, d. Athens, Georgia, June 16, 1878] on March 30, but lack of publication allows credit for the discovery to go to dentist William Thomas Morton [b. Charlton City, Massachusetts, August 9, 1819, d. New York, New York, July 15, 1868] in 1846. Long publishes his own results in 1849. *See also* 1841 MED; 1844 MED.

Physiologist Karl Friedrich Wilhelm Ludwig [b. Wittenhausen, Germany, December 29, 1816, d. Leipzig, Germany, April 27, 1895] shows that the “Malpighian corpuscles” in kidneys act as passive filters. After filtering, waste products become concentrated when they pass through the tubules. *See also* 1953 MED.

Physiologist and physicist Hermann Ludwig Ferdinand von Helmholtz [b. Potsdam, Prussia, Germany, August 31, 1821, d. Charlottenburg, Germany, September 8, 1894] studies the relation between nerve cells and nerve fibers. *See also* 1838 MED; 1849 BIO.

Physics

William Thomson (Lord Kelvin) publishes *On the Uni-*

form Motion of Heat in Homogeneous Solid Bodies

British mathematician and physicist Sir George Gabriel Stokes [b. Skreen, Sligo, Ireland, August 13, 1819, d. Cambridge, England, February 1, 1903] publishes *On the Steady Motion of Incompressible Fluids*. See also 1851 PHY.

Austrian physicist Christian Johann Doppler [b. Salzburg, Austria, November 29, 1803, d. Venice, Italy, March 17, 1853] discovers that the frequency of waves emitted by a moving source changes when the source moves relative to the observer. This newly recognized phenomenon is called the Doppler effect. See also 1845 PHY.

I Tools

William Howe invents the link-motion reversing gear for steam engines. It consists of two eccentrics, one for forward motion and one for backward motion, that alternately can be connected to the valve rod. This system will later be used by Stephenson on locomotives. See also 1763 TOOL; 1844 TOOL.

James Nasmyth discovers that a competitor has copied and built his design for a steam hammer, which Nasmyth had not yet constructed. Credit for the invention is generally assigned to Nasmyth, however (although there is evidence that the first to envision such a tool was James Watt). See also 1839 TOOL.

Thomas Woodward of Brooklyn, New York, patents a form of safety pin that lacks a spring to keep it closed. Instead, it relies on the material being pinned being thick enough to hold the point of the pin in its shield. See also 500 BCE TOOL; 1849 TOOL.

Joseph Whitworth develops an improved planer that is able to cut in both directions. See also 1835 TOOL.

→ Transportation

William Samuel Henson [b. Somerset, England, 1812, d. 1888] in this year and continuing into 1843 designs the “aerial steam carriage,” an early concept for a powered airplane based on the concepts put forth by George

Cayley. See also 1809 TRAN; 1871 TRAN.

Karl von Ghega (b. 1802, d. 1860) begins construction of the first railway over the Alps, linking Vienna and Trieste. The project is completed in 1854. See also 1830 TRAN.

1843

▲ Archaeology

Paul Émile Botta [b. Turin, Italy, 1805, d. Achères, France, 1879] excavates Assyrian sculptures from a mound near Khorsabad (Iraq), the site of an ancient Assyrian city. See also 1845 ARCH.

★ Astronomy

John William Draper takes the first daguerreotype of the solar spectrum. See also 1840 AST; 1849 AST.

In October John Couch Adams [b. Laneast, England, June 5, 1819, d. Cambridge, England, January 21, 1892] calculates the position of what we now call the planet Neptune from irregularities in the orbit of Uranus. See also 1828 AST; 1845 AST.

Heinrich Schwabe discovers a 10-year (later corrected to 11-year) period in the number and activity of sunspots. See also 1825 AST; 1852 AST.

◆ Communication

William Hallowes Miller develops new standard measures for England, replacing the ones destroyed in the fire of the Houses of Parliament in 1834. See also 1824 COMM.

Charles Thurber [b. East Brookfield, Massachusetts, January 2, 1803, d. Nashua, New Hampshire, November 7, 1886] of Worcester, Massachusetts, patents a form of typewriter in which the letters mounted on a wheel can be actuated by pressing directly on the letter. See also 1833 COMM; 1850 COMM.

□ Computers

Ada Lovelace's *Notes* relating her experience with Charles Babbage's Analytical Engine are published. See also 1826 COMP; 1853 COMP.

■ Construction

Marc Isambard Brunel builds the first tunnel under the Thames in London, which opens on March 25. It took 18 years to complete the tunnel, which collapsed several times. Only open to pedestrians, the tunnel is closed 20 years later, and reopened another 20 years later for trains of the London Underground system. See also 1811 CONS.

↗ Energy

Joseph Fowle of Boston develops the first drill powered by compressed air to be used in building tunnels. Within ten years similar drills will be used in mining. See also 1858 COMM.



Baron Kelvin, William Thomson

[b. Belfast, Ireland, June 26, 1824, raised to peerage as Baron Kelvin of Largs, 1892, d. Ayr, Scotland, December 17, 1907]

Kelvin's main accomplishments were in thermodynamics (he coined the word in 1849), where he developed the idea of absolute zero and independently recognized its first and second laws. With James Prescott Joule, Kelvin discovered that gases cool when allowed to expand, the Joule-Thomson effect. Among his best-known work is attributing a far too young age for Earth based on how long the planet would take to cool to its present temperature; Kelvin's error occurred because he calculated this in 1846, a half century before the discovery of radioactivity, which keeps Earth hot. In 1854 Thomson switched his attention to the possibility of laying an underwater telegraph cable across the Atlantic. He became rich when he designed a telegraph receiver, called a mirror galvanometer, for use on the cable, which was successfully laid in 1858. He also invented a compass, an instrument for measuring tides and calculating tide tables, and other devices.



Ada Lovelace (a.k.a. Augusta Ada Byron, or Lady Lovelace)

[b. London, December 10, 1815, d. London, November 27, 1852]

Lovelace was fascinated by Charles Babbage's idea for a new mechanical calculating machine, the Difference Engine. In 1842 Luigi F. Menabrea [b. Chambéry, Savoy, France, September 4, 1809, d. St Cassin, France, May 24, 1896] summarized the concept behind Babbage's more advanced calculating machine, the Analytical Engine. Lovelace translated Menabrea's article into English and added her own notes as well as diagrams and other information. She predicted that such a machine, which Babbage never built, would have many applications beyond arithmetic calculations, from scientific research to composing music and producing graphics. She explained how the machine might be instructed to perform a series of calculations. The programming language ADA is named for her, although the countess has only a slender claim to the frequently used label of "first programmer." But she really did write a program, one for calculating Bernoulli numbers — not a mean feat.

❖ Materials

The steamship *Great Britain*, designed by Isambard Kingdom Brunel, is built largely from wrought iron produced by the puddling process. It is the first oceangoing iron steamer and the first to use a propeller. Despite the fact that it will lay on a beach unpainted for many years, it will still be in good condition in 1988 and the ship will be salvaged and restored as a tourist attraction early in the 21st century. *See also* 1784 MATR.

Σ Mathematics

While walking with his wife along the Royal Canal, Sir William Rowan Hamilton suddenly realizes that he can create a mathematical system that is not commutative (one in which ab does not necessarily equal ba). He is so struck with the idea that he carves this into a pillar of a bridge. This insight leads to the development of quaternions, a mathematical system similar to vectors. *See also* 1844 MATH.

Joseph Liouville announces to the French Academy of Sciences on July 4 that he has found a remarkable proof among the papers of Evariste Galois, who died 11 years earlier in a duel. It is the founda-

tion of group theory. *See also* 1833 MATH.

English mathematician Arthur Cayley [b. Richmond, England, August 16, 1821, d. Cambridge, England, January 26, 1895] introduces "geometry of n dimensions," using determinants. *See also* 1683 MATH; 1851 MATH.

♥ Medicine & health

Author and physician Oliver Wendell Holmes [b. Cambridge, Massachusetts, August 29, 1809, d. Boston, October 7, 1894] advises doctors to prevent spreading puerperal fever (a common disease of mothers after childbirth at the time) by washing their hands and wearing clean clothes. *See also* 1847 MED.

Emil Heinrich du Bois-Reymond [b. Berlin, November 7, 1818, d. Berlin, December 26, 1896] demonstrates that electricity is used by the nervous system to communicate between different parts of the body. *See also* 1840 MED; 1861 MED.

⌘ Physics

Charles Wheatstone develops his Wheatstone bridge, a sensitive device for measuring electrical resistance, and the shunt for electric current, a

device that enables a galvanometer to measure larger electrical currents by removing a definite amount of current from its path. *See also* 1840 PHY; 1878 TOOL.

James Prescott Joule determines the mechanical equivalent of heat by measuring the rise in temperature produced in water by stirring it. *See also* 1840 PHY.

I Tools

Lucien Vidie [b. Nantes, France, 1805, d. Paris, 1866] invents the aneroid barometer, which uses expansion and contraction of an evacuated metal tube to detect changes in air pressure. Unlike previous barometers, the aneroid type indicates atmospheric pressure using a dial and pointer. *See also* 1643 TOOL.

✈ Transportation

George Cayley designs the first aircraft designed to take off vertically, using four propellers, which would then swivel forward for level flight. This craft was never built. *See also* 1804 TRAN; 1853 TRAN.

The clipper ship is introduced by ship designers in the United States. This type of sailing ship is streamlined and

designed for the fast transport of goods. *See also* 1785 TRAN.

1844

★ Astronomy

Irish astronomer William Parsons, third earl of Rosse [b. York, England, June 17, 1800, d. Monkstown, Cork, Ireland, October 31, 1867], after observing the nebula formed by the supernova explosion in 1054, names it the Crab Nebula because of its tentaclelike structure. *See also* 1758 AST; 1928 AST.

Friedrich Bessel, after observing the irregular motion of Sirius and Procyon, concludes that these stars are orbited by invisible companions. *See also* 1841 AST; 1851 AST.

↗ Biology

The anonymous *Vestiges of the Natural History of Creation*, but widely known to have been written by Robert Chambers [b. Peebles, Scotland, 1802, d. 1871], influences the thinking on evolution of both Alfred Wallace and Darwin. Although it contains many errors and does not suggest a mechanism for evolution, *Vestiges* clearly promotes the evolution concept. *See also* 1858 BIO.



CRAB NEBULA The Crab Nebula, named by William Parsons in 1844, has been among the most important astronomical objects for astronomers' understanding supernovae and pulsars. Chinese records show that a "guest star," or supernova, appeared in 1054 where the Crab Nebula is today. Western astronomers also determined the approximate date of the supernova by studying the expansion rate of the nebula. When pulsars were discovered in 1967, one of the first to be observed visually was the central supernova remnant within the nebula.

Darwin outlines in detail for the first time his theory of natural selection in an unpublished essay that runs 231 pages in a fair copy. It is the precursor of his theory of evolution. *See also* 1842 BIO; 1858 BIO.

John William Draper shows that plants when growing in a

solution of sodium bicarbonate liberate oxygen when illuminated. *See also* 1865 BIO.

Rudolf von Kölliker shows that the egg is a cell and that all cells in an organism originate by divisions from the egg cell. *See also* 1882 BIO.

Gabriel Gustav Valentin discovers that pancreatic juice breaks down food in digestion. *See also* 1838 BIO.

Chemistry

Physicists Léon Foucault and Armand Hippolyte Fizeau [b. Paris, September 23, 1819, d. Venteuil, France, September 18, 1896] formulate the theory of allotropy, explaining how crystals can exist in two or more forms. *See also* 1841 CHEM.

Russian chemist Carl Ernst Claus [b. Tartu (Estonia), January 23, 1796, d. Tartu, March 24, 1864] discovers the chemical element ruthenium (Ru).

Communication

Werner von Siemens develops a mechanical copying method based on reproducing printed matter with zinc plates in which the part to be reproduced is raised into relief. *See also* 1842 MATR.

Samuel F. B. Morse uses his telegraph system to send a famous message from Washington to Baltimore: "What hath God wrought?" The message is received by Alfred Vail, who is credited by some with inventing the Morse code. *See also* 1837 COMM.



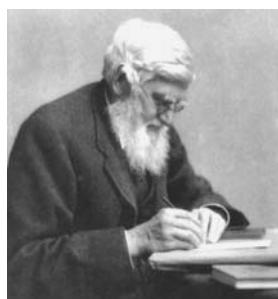
Léon Jean Bernard Foucault

[b. Paris, September 18, 1819, d. Paris, February 11, 1868]

From 1849 through 1862 Foucault studied the speed of light, first collaborating with Armand Fizeau in determining an improved value and then in 1850 finding the speed of light in water. Because the speed in water is slower than in air, Foucault's work confirmed that light behaves as a wave (today it is recognized that light also behaves as a particle). In 1851 Foucault constructed the first of several large pendulums with which he demonstrated experimentally that Earth rotates on its axis. As an outgrowth of his work with pendulums, he invented the gyroscope (in 1852).

Earth science

Darwin's *Geological Observations on Volcanic Islands Visited during the Voyage of H.M.S. Beagle*, being the second part of the geology of the *Beagle*, confirms that Lyell's theories apply to places that Lyell has never visited. *See also* 1842 EAR.



Alfred Russel Wallace

[b. Monmouthshire, England, January 8, 1823, d. Broadstone, Dorset, England, November 7, 1913]

Alfred Wallace is best known as the codiscoverer, with Darwin, of evolution by natural selection. In 1854 Wallace set out on a collecting expedition to the Malay Archipelago. During his travels he decided that the geographical distribution of species results from evolutionary forces. In 1858 he sent an essay containing his ideas to Darwin who, unknown to Wallace, had been developing a similar theory for some 20 years. Darwin presented a joint paper on their theory before the Linnaean Society on July 1, 1858. Wallace also did pioneering work in zoogeography (the study of the geographic distribution of animals), including the observation of two distinct zoological regions in the Malay Archipelago separated by what came to be called Wallace's line.

The telegraph

Fires, smoke signals, and drums have been used since antiquity to transmit messages over long distances. The term *telegraph* was coined by Claude Chappe to describe such methods, a version of which was invented by him and his brothers to signal each other while in school. In 1793 Chappe introduced in France a form of this system for the transmission of messages based on stations with towers using a code to transmit signals by the position of crossed arms. Today this kind of system is called a semaphore ("sign bearer"), not a telegraph ("far writer").

The idea of the electric telegraph was born when the first experimenters with electricity noticed that electric charges could travel through wires over distances. In 1753 in Scotland Charles Morrison described a system of 26 wires for transmitting the 26 letters of the alphabet. Electrostatic charges traveling through these wires deflected suspended pith balls at the receiving station. However, this was never developed as a practical system.

During the early 19th century, several scientists experimented with the transmission of messages through electric wires. At this time scientists had gained access to a steady, low-voltage source of electricity. Karl Friedrich Gauss and Wilhelm Weber transmitted signals over wires and detected them with sensitive galvanometers around 1833. In England Charles Wheatstone developed a telegraph with a five-needle galvanometer that indicated the transmitted letters. The Wheatstone telegraph actually came into use, linking Liverpool with Manchester in 1839. In Germany Carl Steinheil developed a telegraph that printed coded messages on a ribbon.

The electromagnet, a magnet whose field appears when current is on and disappears when it is off, was discovered in the 1820s. The American painter Samuel Morse first became acquainted with an electromagnet when it was shown to him by a young chemist he met on a transatlantic ship. Morse realized

that a magnet turning on and off by transmission of a current from a distant source could be used to send messages. He soon enlisted America's greatest scientist of the time, Joseph Henry, to develop ways to cause an electromagnet to work at a distance. The electric telegraph became truly functional with the idea of using a code of dots and dashes to transmit the letters of the alphabet; this method was conceived by another collaborator, the American engineer Alfred Vail.

Despite this technical help, Morse is given credit for the invention because he put together a practical system and got people to accept it.

Morse patented his telegraph in 1837 and officially inaugurated a link between Baltimore, Maryland, and Washington, DC, on May 14, 1844, by transmitting the message "What hath God wrought." The message was transmitted by a telegraph key, a special switch that allows an electric current to be rapidly switched in and out; it was printed in the dot-dash code on ribbons of paper. In 1844 Vail determined that an operator could learn to hear the differences between dots and dashes; this became the preferred way to decipher messages.

Morse's telegraph quickly spread in the United States, and later it superseded the existing systems of Wheatstone and Steinheil in Europe. In 1862, 240,000 km (150,000 mi) of telegraph cable covered the world, of which 77,000 km (48,000 mi) were in the United States and 24,000 km (15,000 mi) in Great Britain. Europe and the United States became linked by an underwater telegraph cable in 1866.

During the 20th century, the use of the telegraph declined, mainly because of lower prices for telephone and telex services. Also, wireless telegraphy, the first form of radio that used the same codes as ordinary telegraphy, was available. "Telegrams" increasingly were transmitted by telex or telephone instead of as actual telegrams. During the 1980s telegraph services disappeared altogether in most countries.

The American explorer Charles Wilkes [b. New York City, April 3, 1798, d. Washington, DC, February 8, 1877] publishes a report of the U.S. Exploring Expedition (1838–42) to Antarctica and the Pacific Northwest. *See also* 1820 EAR; 1912 EAR.

Ecology & the environment

The Commission for Enquiring into the State of Large Towns and Populous Districts

is told by several physicians that there is a direct connection between dirty air and epidemic disease in England. *See also* 1800 MED; 1854 MED.

Energy

An experimental electric light is installed on the Place de la Concorde in Paris. *See also* 1841 ENER; 1845 ENER.

William Fairbairn [b. Kelso, Scotland, February 19, 1789, d. Moor Park, England,

August 18, 1874] and John Hetherington patent what comes to be called the Lancashire boiler. It consists of a cylindrical vessel through which passes a cylindrical flue; this type of boiler remains in use until the 20th century.

Mathematics

Die lineale Ausdehnungslehre, ein neuer Zweig der Mathematik ("linear extension theory, a new branch of mathematics") by German

mathematician Hermann Günther Grassmann [b. Stettin (Szczecin, Poland), April 15, 1809, d. Stettin, September 26, 1877] introduces vectors in more than three dimensions, but this concept is poorly understood by his contemporaries. Grassmann also develops an algebra in which symbols representing geometric entities (points, lines, and planes) are manipulated according to specific rules. *See also* 1843 MATH; 1881 MATH.

Joseph Liouville establishes that transcendental numbers exist. Transcendental numbers are numbers such as π and e that are not solutions of algebraic equations with rational coefficients. Liouville's transcendental numbers are typified by the number 0.10100100010000100000100000... , in which the number of zeros between ones increases regularly. *See also* 1873 MATH.

Augustin Cauchy proves a fundamental theorem in group theory that had been asserted by Galois (every finite group whose order is divisible by a prime p contains a subgroup of order p), while investigating permutation groups. *See also* 1833 MATH.

♥ Medicine & health

Dentist Horace Wells [b. Hartford, Connecticut, 1815, d. January 28, 1848] is the first to use nitrous oxide as an anesthetic in dentistry. *See also* 1846 MED.

Charles Thomas Jackson suggests using ether to deaden pain to dentist William Thomas Morton. *See also* 1841 MED; 1846 MED.

I Tools

Belgian mechanic Egide Walschaerts [b. Malines, Belgium, January 21, 1820, d. 1901] invents a reversing gear for steam railway locomotives using only one eccentric. It becomes universally adopted on steam locomotives later in the century. *See also* 1842 TOOL.

→ Transportation

John Ericsson builds a propeller-driven, metal-hulled warship, the *Princeton*, which has its engines below the water

line for better protection. *See also* 1839 TRAN; 1851 TRAN.

1845

▲ Archaeology

Sir Austen Henry Layard [b. Paris, March 5, 1817, d. London, July 5, 1894] begins to excavate the ruins of Nineveh (Iraq), the capital of Assyria that had fallen to Babylon and the Medes in 612 BCE. *See also* 1843 ARCH; 1870 ARCH.

★ Astronomy

William Parsons (Lord Rosse) at Birr Castle in Ireland completes a 183-cm (72-in.) reflecting telescope, known as the Leviathan, that he had begun in 1843. The tube used to direct light to the 3–4 metric ton (3.8 ton) mirror is 17.7 m (58 ft) long. Because of the Irish potato famine it does not go into service until 1847. Its first application is to chart newly observable details on the Moon, followed by similar maps of the planets Jupiter, Saturn, and Mars. It will be the largest telescope on Earth until 1917, although it will be taken out of service and dismantled in 1908 but later reactivated. *See also* 1789 AST; 1850 AST.

Astronomer Urbain Jean Joseph Le Verrier [b. St. Lô, Manche, France, March 11, 1811, d. Paris, September 23, 1877], independently of John Couch Adams, uses small irregularities in the orbit of Uranus to postulate the existence and position of an eighth planet, found the next year by Johann Galle and named Neptune.

Edgar Allan Poe [b. Boston, January 19, 1809, d. Baltimore, October 7, 1849] is one of the first to give an explanation of why the night sky is dark by

assuming that the universe has a finite age. This question is known as Olbers' paradox since an infinite universe would imply a night sky filled equally with light at all points, instead of individual stars.

❖ Biology

German clergyman Johannes Dzierzon [b. 1811, d. 1906] finds that among bees the drones hatch from unfertilized eggs while queens and worker bees hatch from fertilized eggs.

German physician Robert Remak [b. Posen (Poznán, Poland), July 30, 1815, d. Kissingen, Germany, August 29, 1865] corrects Karl Ernst von Baer's theories of the development of the embryo by showing that there are only three layers present in the early development, which he names the ectoderm, mesoderm, and endoderm. *See also* 1828 BIO; 1861 BIO.

▷ Chemistry

German chemist Adolph Wilhelm Hermann Kolbe [b. Elliehausen, Germany, September 27, 1818, d. Leipzig, Germany, November 25, 1884] synthesizes acetic acid from nonorganic compounds. *See also* 1828 CHEM.

Edward Frankland [b. Churchtown, England, January 18, 1825, d. Golaa (Norway), August 9, 1899] estimates that about 20 people are trained in chemistry per year in England and none in physics.

⌚ Communication

Alfred Ely Beach [b. Springfield, Massachusetts, September 1, 1826, d. January 1, 1896] founds *Scientific American*, a U.S. science magazine for the general reader.

The telegraph developed by Charles Wheatstone attracts publicity when it results in the arrest of the "Quaker murderer." The suspect is spotted on board the London-bound train at Slough and, as a result of a telegram, arrested when he arrives at Paddington station. *See also* 1837 COMM; 1910 COMM.

The first underwater telegraph cable is laid under the Hudson River between New York City and Fort Lee, New Jersey. *See also* 1851 COMM.

■ Construction

John Augustus Roebling completes the first suspension aqueduct in the United States, which carries the Pennsylvania State Canal across the Allegheny River near Pittsburgh, Pennsylvania. *See also* 1841 MATR; 1855 CONS.

Work begins on the library of Sainte Geneviève in Paris, designed by Henri P.F. Labrouste [b. Paris, May 11, 1801, d. Fontainebleau, France, June 24, 1875], the first public building in which iron is used as part of the visible style, with iron vaults and columns. Overall the building combines the "modern" style, using the uncovered iron, with more traditional features. *See also* 1851 CONS.

▼ Energy

In England Thomas Wright obtains the first patent for an arc lamp, which uses automatic adjustment to keep the carbon rods the proper distance apart. William Staite patents an arc lamp that uses variations in current to keep the light even. Neither becomes commercially available. *See also* 1809 ENER; 1876 ENER.

William Fairbairn introduces the riveting machine to the manufacture of steam boilers. He also designs and builds tubular steel railway bridges.

Charles Wheatstone develops an electric generator in which electricity is induced in coils by an electromagnet powered by a battery. Later he will power these magnets with the current from the generator itself. *See also* 1838 ENER.

Food & agriculture

Thomas Scragg invents a machine for making drainpipe that greatly facilitates land drainage in Britain.

Peter Cooper [b. New York City, February 12, 1791, d. New York City, April 4, 1883], better known as the manufacturer of the locomotive Tom Thumb and the benefactor of Cooper Union, invents the first gelatin dessert. *See also* 1897 FOOD.

A potato blight, which had first appeared in Europe about 1840, devastates Ireland, which had come to depend on this American species as a staple. It is caused by a fungus. *See also* 1885 FOOD.

Materials

John Mercer [b. Dean, England, February 21, 1791, d. November 30, 1866] discovers that cotton thread soaked in a

solution of sodium hydroxide becomes heavier and shiny, a process now called mercerization. *See also* 1756 MATR.

Thomas Hancock [b. Wiltshire, England, May 8, 1786, d. London, March 26, 1865] invents ebonite, created by treating rubber with sulfur. It becomes widely used as an electrical insulator. *See also* 1839 MATR.

August Wilhelm von Hofmann [b. Giessen, Germany, April 8, 1818, d. Berlin, May 2, 1892] develops a method for preparing aniline dye from benzene. *See also* 1826 CHEM; 1856 MATR.

Medicine & health

Rudolf Virchow is the first physician to describe leukemia.

Jacques-Joseph Moreau de Tours is the first to describe psychosis caused by hashish (cannabis), although he also suggests physical and mental benefits. *See also* 1812 MED.

Physics

Michael Faraday relates magnetism to light after finding that a magnetic field affects polarization of light in crystals. He proposes that light may be waves of electromagnetism. He also discovers diamagnetism (opposition to a magnetic field) and paramagnetism (response to a magnetic field),

explaining each in terms of his field concept. *See also* 1873 PHY.

Dutch meteorologist Christopher Buys-Ballot [b. 1817, d. 1890] performs an experiment with trumpeters on a train confirming the Doppler effect. *See also* 1842 PHY.

John Herschel finds that certain substances (for example, quinine sulfate or fluorspar) give off visible blue light when irradiated with ultraviolet radiation. *See also* 1801 PHY; 1895 PHY.

Tools

An Italian manufacturer produces the first breech-loaded cannon of modern times using a sliding-wedge design. This is quickly followed by other manufacturers using either the sliding wedge or an interrupted screw to prevent the explosion from forcing out the rear of the cannon. *See also* 1461 TOOL.

In England the percussion tube is invented. It provides a way to ignite powder by pulling a rope that releases a hammer that explodes a tube of percussion powder, which then sets off the main charge of a cannon. *See also* 1807 CHEM.

Transportation

Joseph Francis, who has developed a wooden lifeboat that uses a cable that attaches to

shore when the lifeboat aids a sinking vessel, finds that the cable is not strong enough in actual practice. After much experimentation he patents a method of making boats out of corrugated iron that proves practical in other floating devices, such as docks and buoys. *See also* 1819 TRAN.

Scottish engineer Robert William Thomson [b. Stonehaven, Scotland, 1822, d. Edinburgh, March 8, 1873] invents and patents the vulcanized, air-filled rubber tire, but is unable to market it because it is viewed as too expensive. *See also* 1888 TRAN.

1846

Archaeology

Ephraim George Squier [b. Bethlehem, New York, 1821, d. Brooklyn, New York, 1888] and Edward Hamilton Davis explore the mounds built by American Indians in the Mississippi River valley, locating among other great mounds the Serpent Mound in Adams County, Ohio, near Peebles. The mound is about 6 m (20 ft) wide, 1.5 m (5 ft) tall, and 405 m (1330 ft) long in the shape of a snake eating an egg. *See also* 1784 ARCH.

Excavations begin on an ancient Bronze/Iron Age graveyard at Hallstatt, Austria, which over the next 20 years is dated as having been active from 800 to 400 BCE, the first actual dates established for the transition from the Bronze to the Iron Age.

Henry Creswicke Rawlinson publishes his deciphered version of the part of the Behistun inscriptions that is in Persian cuneiform. *See also* 1837 ARCH.



Rudolf Carl Virchow

[b. Schivelbein, Pomerania (Poland), October 13, 1821, d. Berlin, September 5, 1902]

Virchow's many discoveries include cells in bone and connective tissue; substances, such as myelin; and pathologies, such as embolism and leukemia. In 1855 he published his now-famous aphorism *omnis cellula e cellula* ("every cell stems from another cell"). He also stated that all diseases involve changes in normal cells — that is, all pathology ultimately is cellular pathology.



GREAT SERPENT MOUND Because of its great length, it is hard to imagine how early Native American mound builders conceived of or observed the Great Serpent Mound, one of a number of effigy mounds found throughout the Midwestern United States. This mound may have been built as part of a rattlesnake cult dated at about 950 to 1200 CE. Ordinary mounds in the shape of conical hills, used for burial, were once nearby, but may have been made by a different early group of Native Americans from those who constructed the serpent mound.

★ Astronomy

On September 23 Johann Galle discovers the planet Neptune using the predictions of its position by Urbain Le Verrier and John Couch Adams along with Bode's Law. *See also* 1781 AST; 1930 AST.

Astronomer William Lassell [b. Bolton, England, June 18, 1799, d. Maidenhead, England, October 5, 1880] discovers Triton, Neptune's large satellite. *See also* 1787 AST; 1848 AST.

The comet named after Wilhelm von Biela splits into two pieces. *See also* 1826 AST.

Macedonio Melloni, [b. Parma (Italy), April 11, 1798, d. near Naples, August 11, 1854] measures the heating effect produced by sunlight reflected from the Moon that reaches Earth during the night. *See also* 1856 AST.

◆ Biology

Botanist Hugo von Mohl [b. Stuttgart, Baden-Württemberg (Germany), April 8, 1805, d. Tübingen, Baden-Württemberg, April 1, 1872] gives the term *protoplasm* ("earliest former") the sense it will have for a long time, identifying it as the principal substance of a cell. Modern cell biologists, however, change the name to *cytoplasm* ("cell former") to avoid the implication that the substance existed before cells themselves existed. *See also* 1839 BIO; 1850 BIO.

Lehrbuch der vergeleichenden Anatomie ("textbook of comparative anatomy") by Karl Theodor Ernst von Siebold [b. Würzburg (Germany), February 16, 1804, d. Munich, Bavaria, April 7, 1885] recognizes that protists are made from a single cell. Siebold also claims, incorrectly, that pro-

tists form the basis of other organisms. *See also* 1866 BIO.

Karl Wilhelm von Nägeli [b. Kilchberg, Switzerland, March 27, 1817, d. Munich, Germany, May 10, 1891] shows that plant cells are not formed as buds from the surfaces of existing cells, as had been proposed by Theodor Schwann. *See also* 1839 BIO; 1855 BIO.

◆ Communication

The Smithsonian Institution is founded in Washington, DC, with a £100,000 bequest from English chemist and mineralogist James Smithson [b. France, 1765, d. Genoa, Italy, June 27, 1829]. Joseph Henry is elected first secretary of the institution.

Alexander Bain develops a method of sending telegraph messages using punched paper tape, greatly improving the speed of transmission. *See also* 1840 COMM.

◎ Earth science

William Thomson (Lord Kelvin) uses the temperature of Earth to determine (incorrectly) that Earth is about 100,000,000 years old. He does not take into account heat from radioactivity, which was unknown at this time, which makes his estimate very short of the true age. *See also* 1862 EAR; 1907 EAR.

◆ Energy

John William Draper patents an incandescent electric lamp with a platinum filament. *See also* 1845 ENER; 1850 ENER.

◆ Materials

Christian Schönbein discovers nitrocellulose, an explosive, when he accidentally wipes up a spilled acid solution with his

wife's cotton apron, which vanishes in a puff as it dries. *See also* 1838 MATR; 1863 MATR.

Louis Nicolas Menard [b. Paris, October 19, 1822, d. Paris, February 9, 1901] discovers collodion by dissolving nitrocellulose in a mixture of alcohol and ether. A number of other chemists independently discover essentially the same substance about this time, notably American J. Parkers Maynard (in 1848). *See also* 1855 MATR.

Σ Mathematics

Scottish mathematician and physicist James Clerk Maxwell completes his first scientific paper at age 14, "On the Description of Oval Curves, and Those Having a Plurality of Foci."

Evariste Galois' paper on group theory is finally published by Joseph Liouville in October, more than 14 years after his death. *See also* 1833 MATH; 1870 MATH.

▼ Medicine & health

William Thomas Morton uses ether as an anesthetic during operations as advised by Charles Thomas Jackson, who discovered that ether is an anesthetic. *See also* 1844 MED.

A measles epidemic occurs in the Faeroe Islands. A study of how the disease progresses from person to person and island to island by Dutch physiologist Peter Ludwig Panum [b. 1820, d. 1885] is a classic in epidemiology.

Scottish obstetrician Sir James Young Simpson [b. Bathgate, Scotland, June 7, 1811, d. London, May 6, 1870] discovers that chloroform is a better anesthetic than ether or nitrous oxide; he starts the use

Predicting the planets

The ancients knew the planets Mercury, Venus, Mars, Jupiter, and Saturn (and Earth, although they did not think of it as a planet). Some of them offered reasons why there were these and no more. Pythagoreans, for example, argued on the basis of number properties. Much later, Johannes Kepler claimed that the number of planets is fixed by the number of the five regular solids. The world was astounded, then, when William Herschel discovered a seventh planet, Uranus, in 1781.

In fact, Uranus had been seen by other astronomers for years. It can be seen with the naked eye and had even been included on star maps. Since no one expected a new planet, however, it had gone unidentified as one. Herschel was the first observer whose telescope was good enough to reveal the "star" as a disk. (All stars except the Sun are so far away that they appear as points in even the largest telescopes.)

Herschel's discovery was the result of his systematic searching of the sky, his good telescope and good vision, and a certain amount of luck. The other two planets, Neptune and Pluto, that have been discovered since were both predicted. Nevertheless, the same qualities, especially the luck, were vital in finding each.

In 1821 Alexis Bouvard used all the known sightings of Uranus to calculate its orbit. The calculations from earlier sightings could not be made to agree with later ones, however. Something was wrong.

Something was wrong with Mercury's orbit, also. Like that of Uranus, the orbit of Mercury could not be made to fit with Newton's laws. Either Newton was not quite correct or there must be other bodies, most likely planets, near enough to Mercury and Uranus to affect their orbits. Most astronomers felt strongly that Newton must be correct and that other planets would be found.

Among the first to calculate the position of such a planet was Urbain Le Verrier in 1845. He predicted a planet inside the orbit of Mercury. He even named the planet — Vulcan. A few astronomers had been searching for such a planet already. Even with the help of Le Verrier's calculations, no planet was found.

In 1843 John Couch Adams determined the position of a planet outside the orbit of Uranus. But when he offered his calculations to the astronomer royal, George Airy, Airy paid no attention. Airy was one of the few astronomers who thought the irregularities were caused by defects in Newton's theory.

In 1845, although disappointed in the search for Vulcan, Le Verrier also turned to the planet beyond Uranus. He produced

essentially the same result as Adams had. Unlike Adams, however, Le Verrier took his calculations to someone who was willing to conduct the search. Johann Gottfried Galle immediately found a planet where Adams and Le Verrier had said it would be, although at a different distance. Both calculators had relied on Bode's law to locate the planet, but the "law" is apparently the result of chance and does not apply to the new planet, which Le Verrier named Neptune.

Neptune had actually been seen earlier, but not recognized. The earliest sighting came on January 27, 1613, when Galileo recorded two stars in his field of view. One was Neptune and the other a genuine star. When he observed the pair again the following night, Galileo noted that the two "stars" appeared to be farther apart. Had Galileo followed up on the observations, he would have been the first to discover a planet.

When the orbit of Neptune was calculated from these observations, it became clear that Le Verrier and Adams were also lucky. Neptune could not account for all of the deviations in the orbit of Uranus after all. Furthermore, Neptune's orbit also deviated.

Scientists set out to find the next planet, which they believed would resolve these problems. The most dedicated was Percival Lowell, but he was unable to find a planet either by calculation or observation. Lowell even built his own observatory.

After Lowell's death in 1916, the search continued at Lowell Observatory. Finally, Clyde Tombaugh located a "star" on a pair of photographs that was in a slightly different place from one day to the next. He had found Pluto.

As usual, a lot of luck as well as systematic work went into the discovery. However, finding Pluto did not solve the problems with the orbits of Uranus and Neptune. For one thing, Pluto is too small. Many astronomers today think that Pluto, instead of being the smallest planet, is not a planet at all, but a kind of cross between a comet and an asteroid known as a Kuiper Belt Object. There are very many other Kuiper Belt Objects, although Pluto seems to be the largest. In 2001 the odd orbit of Comet 2000 CR₁₀₅ suggested to Brett Gladman of the Observatoire de la Côte d'Azur in Nice, France, that a planet the size of Mars or larger might lurk in the Kuiper Belt — or that it was there at some time in the past. Another possible explanation for the comet's path would be that Neptune had a different orbit in the past and that while in that orbit it had disturbed the comet's orbit.

By the way, in 1915 Albert Einstein developed a new theory of gravity, one that superseded Newton's. In Einstein's theory, Mercury's orbit was perfectly all right. There was no need for a planet to perturb it.

of chloroform in childbirth. In 1847 his *Account of a New Anesthetic Agent* will describe his discovery. See also 1844 MED; 1884 MED.

✿ Physics

James Prescott Joule discovers that the length of an iron bar changes slightly when the bar

is magnetized, a phenomenon now called magnetostriction. See also 1845 PHY; 1861 COMM.

Wilhelm Weber works out a

system of inferring the magnetic force on a single charged particle caused by a current and a logical system of fundamental units for electricity.

Nitrogen: A matter of life and death

We live in a sea of elemental nitrogen, since nearly four out of five air molecules are two nitrogen atoms joined by a chemical bond. Despite this apparent oversupply, the availability of nitrogen in a more usable form has been in one way or another a major problem to humans for the past 10,000 years and perhaps much longer than that. To understand why, it helps to consider nitrogen chemistry, its importance to living creatures, and the normal nitrogen cycle in the environment.

A combination of nitrogen and hydrogen is the "amino" of amino acids, the twenty-odd compounds that form all the proteins in the body. The NH₂ amino radical converts an organic acid of carbon, oxygen, and hydrogen into a unit that easily links via the nitrogen atom with other amino acids. Such polymers of amino acids, which are the proteins, are not only the building blocks of life, as we were taught in school, but also the enzymes that cause the processes of life to take place. Furthermore, genes rely on nitrogen atoms.

Nitrogen is essential for life and it is abundant in air, but there is a catch. Ordinary chemical processes do not remove nitrogen from the air. With five electrons in its outer shell, the nitrogen atom seeks three more to form a stable molecule. Consequently, two nitrogen atoms forming a molecule arrange to share three of their outer electrons, giving the molecule a triple bond instead of the more common double bond. Each atom treats three of the electrons belonging to the other atom as its own, so each atom can claim eight outer electrons. Such a triple bond is hard to break. Before life existed on Earth, there was only one force strong enough to split the nitrogen molecule — lightning. Freed from each other in a lightning stroke, some of the nitrogen atoms grab an oxygen atom or hydrogen atom (from water vapor) or both. The resulting nitric acid or nitrogen oxides eventually wind up on Earth. Some of the nitric acid reacts with sodium or potassium to form a soluble mineral.

Nitrogen compounds from lightning or from mineral deposits were sufficient to get life started nearly 4,000,000,000 years ago. Subsequently, some bacteria developed another way to obtain nitrogen from the air. This cannot be easy to do, as no other living creatures have evolved with such an ability. Some plants, however, have made suitable living arrangements with the bacteria, providing homes for the bacteria in return for nitrogen rent.

Long before any of this was known by people, farmers had developed processes to put more nitrogen into soil. They learned that growing the same plant in a field each year (unless it harbored nitrogen-fixing bacteria), and removing the plant with its nitrogen to use for food or fodder, resulted in poor crops after a

few years. Practices to sustain nitrogen in the soil developed, notably crop rotation and the use of animal manure as fertilizer. Although animals need nitrogen, their diet nearly always contains far much more than is required, so animals regularly excrete nitrogen.

As the human population increased, the need for nitrogen to grow plants grew faster than local supplies. A major source of nitrogen in the 19th and early 20th centuries was guano, highly nitrogenous bird waste from islands off Peru. Lack of rainfall and large nesting populations of seabirds had produced mountains of guano over thousands of years. After exploitation began, the guano was mined faster than it was deposited.

Also during the 19th century, an important new use for nitrogen compounds emerged. Many nitrogen compounds contain large amounts of oxygen bound loosely to the compound. A small amount of heat or even a light tap can provide enough energy to release some of the oxygen, which then combines with other elements, producing more energy along the way. The result is a sudden explosion. Such a reaction is at the heart of gunpowder, where potassium nitrate gives the mixture its kick. In 1846 an even more explosive combination of nitrogen and cellulose was found by accident; this discovery set off a wave of development that led to nitroglycerin, dynamite, TNT, plastic explosives, and other blasting compounds. As a result, nitrogen is coveted by generals and farmers alike.

Getting nitrogen from the air is the obvious solution, but the only way known to do this during the 19th century was by imitating lightning. Although generation of electricity in large amounts began at the end of the century, efforts to produce nitrogen this way were not very effective.

Shortly before World War I, two patriotic Germans solved the problem of fixing nitrogen, with Fritz Haber working out the basic chemistry and Karl Bosch developing a manufacturing process. Bosch's first big plant was finished shortly after the start of the war. Before the Haber-Bosch process, the best source of nitrogen for explosives had been potassium nitrate, found in the driest desert in the world in Chile — a long way from Germany and easily defended. If it had not been for the Haber-Bosch process, Germany would have run out of ammunition in 1916 and would have had to surrender. Instead, the war went on until Germany was defeated by superior force. (Haber had developed poison gases that almost turned the tide in Germany's favor; a few years after the war, Haber had to leave his beloved Germany because he was a Jew.)

Since World War I the Haber-Bosch process has contributed both to fertilizer and explosives production. Even as fertilizer, nitrogen compounds have proven to be a mixed blessing. Runoff from heavily fertilized farmland has polluted lakes and streams.



James Clerk Maxwell

[b. Edinburgh, Scotland, June 13, 1831, d. Cambridge, England, November 5, 1879]

Much of Maxwell's early work was based on interaction of moving particles. In 1857 he showed that Saturn's rings must consist of small particles. Three years later he determined the statistical distribution of moving molecules in gases, explaining diffusion and conduction of heat (this theory was independently derived by Ludwig Boltzmann). Maxwell also studied color, being the first to show that the primary colors of light are red, green, and blue and demonstrating the first color photograph based on this idea. From 1856 through 1873 Maxwell developed the laws of electromagnetism, beginning with Michael Faraday's concept of a field of lines of force. Maxwell's calculations showed that electromagnetic waves in a vacuum travel at the same speed as light; he correctly concluded that light is a form of electromagnetic wave, boldly predicting the rest of the electromagnetic spectrum.

I Tools

Elias Howe [b. Spencer, Massachusetts, July 9, 1819, d. Brooklyn, New York, October 3, 1867] patents the lock-stitch sewing machine. *See also* 1830 TOOL; 1851 TOOL.

Erastus Brigham Bigelow [b. Boylston, Massachusetts, 1814, d. Boston, December 6, 1879] develops a power loom that produces carpets and tapestries at greater speed than earlier looms and that allows the incorporation of nonsymmetrical patterns, such as flowers. *See also* 1813 TOOL.

A French gunsmith named Houiller develops the first true one-piece cartridge for small arms, a charge of powder in a case with a percussion cap and a projectile, all in one waterproof package. An essential part of his invention is a mechanism for removing the case when the cartridge has been fired. *See also* 1809 MATR.

→ Transportation

Daniel Gooch builds the Great Western, the most powerful locomotive of its time with a boiler operating at 100 pounds per square inch (psi) pressure and reaching average speeds of 107 km/h (67 mi/h). *See also* 1840 TRAN.

The Gauge Act, enacted in England, fixes the distance

between rails; this gauge is adopted by all the other European nations except Spain and Russia. *See also* 1830 TRAN.

Regular passenger service on steamships is established across the Atlantic Ocean between Great Britain and North America; packet service had preceded this for several years. *See also* 1838 TRAN.

1847

▲ Archaeology

Jens Jacob Worsaae [b. Denmark, 1821, d. 1885] becomes the first professional archaeologist, appointed by the king of Denmark to be the archaeologist royal.

★ Astronomy

John Herschel's *Results of Observations at the Cape of Good Hope* completes the survey of the southern sky started by Edmond Halley. Herschel is the first to measure the brightness of stars with true precision. *See also* 1679 AST.

American astronomer Maria Mitchell [b. Nantucket, Massachusetts, August 1, 1818, d. Lynn, Massachusetts, June 28, 1889] discovers a comet on October 1, calling attention to the role of American women in science. *See also* 1797 AST; 1848 COMM.

❖ Biology

Wilhelm Friedrich Benedikt Hofmeister [b. Leipzig, Germany, May 18, 1824, d. Leipzig, January 12, 1877] describes in detail how a fertilized plant ovule develops into an embryo. *See also* 1842 BIO.

Missionary and physician Thomas Savage [b. 1804, d. 1880] and comparative anatomist Jeffries Wyman [b. Chelmsford, Massachusetts, August 11, 1814, d. Bethlehem, New Hampshire, September 4, 1874] give the first detailed description of gorillas.

Carl Bergmann [b. 1814, d. 1865] observes that within a single species of warm-blooded animal, populations with less massive individuals are found more often in warm climates while those with greater mass are found in cooler regions. This occurs because big animals generally have more cells, resulting in more heat being produced. Thus, body weight tends to a minimum in warmer regions, increases to a certain threshold as temperature declines, then falls off again as temperature falls further and there is a need to reduce heat loss (since the surface area to volume ratio is less in larger animals).

▷ Chemistry

German chemist Lambert von Babo [b. 1818, d. 1899] dis-

covers that the addition of a nonvolatile solute to a liquid decreases its vapor pressure in an amount proportional to the amount of solute (Babo's law). *See also* 1885 CHEM.

↳ Communication

Frederick Bakewell invents a way of electrically transmitting a picture painted with shellac from one conducting roller to another roller connected to the first by wire. The invention is an early form of facsimile machine. However, synchronization of the drums at each end is a considerable problem. The invention is not used commercially. *See also* 1840 COMM; 1863 COMM.

Richard March Hoe [b. New York City, September 12, 1812, d. Florence, Italy, June 7, 1886] invents both the rotary and web printing presses. His rotary presses reach a capacity of 18,000 sheets printed on both sides per hour. Their invention contributes to the rapid spread of large-circulation newspapers. The *Philadelphia Public Ledger* is the first newspaper to use Hoe's rotary press. *See also* 1814 COMM.

Abel Nièpce de Saint-Victor [b. Saint Cyr, France, 1805, d. 1870] introduces the aluminized glass plate to photography. All previous photo-

tographs used metal, paper, or even asphalt, but the glass plate produces finer images and remains popular until celluloid is introduced. *See also* 1839 COMM; 1851 COMM.

Sir David Brewster develops an improved stereoscope. Two photographs are taken from slightly different angles. The stereoscope causes each eye to view just one of the images. This gives the viewer an impression of three dimensions when the two different images are combined into one by the brain. *See also* 1838 COMM.

Energy

Werner von Siemens suggests that gutta percha be used to preserve electrical wiring from moisture, an idea that leads to the first underground and submarine telegraph cables. *See also* 1850 COMM.

Materials

Ascanio Sobrero [b. Casale (Italy), October 12, 1812, d. Turin, Italy, May 26, 1888] discovers the explosive nitroglycerine. Sobrero, a trained medical doctor, also finds the compound to have medical uses, notably in controlling some forms of heart irregularities and the pain of migraine. *See also* 1838 MATR; 1863 MATR.

Mathematics

Geometrie der Lage (“geometry of position”) by Karl Christian von Staudt [b. Rothenburg (Germany), January 24, 1798, d. Erlangen, Germany, June 1, 1867] redevelops projective geometry without regard to lengths or numbers, demonstrating that in some sense it is more fundamental than Euclidean geometry (which becomes a special case of projective

geometry that also requires congruence). *See also* 1832 MATH; 1852 MATH.

Ernst Eduard Kummer [b. Sorau (Germany), January 29, 1810, d. Berlin, May 14, 1893] introduces the concept of an ideal complex number into number theory. This is a generalization of the concept of prime numbers that makes the fundamental theorem of arithmetic (that all integers can be factored into primes in only one way) applicable to complex numbers. In May Kummer writes Joseph Liouville to describe his invention of ideal complex numbers, an important step in modern number theory and also a step toward the development of modern algebra with its emphasis on structures, such as rings. In October Kummer uses his concept of ideal complex numbers to show that Fermat’s “last theorem” holds true for a large — possibly infinite — class of prime-number exponents, the regular primes. *See also* 1839 MATH; 1995 MATH.

George Boole [b. Lincoln, England, November 2, 1815, d. Ballintemple, Ireland, December 8, 1864] publishes his first ideas on symbolic logic in *The Mathematical Analysis of Logic*, in which he lays a mathematical foundation to the rules of logic. Boole’s version of symbolic logic will later become the basis of computer design. *See also* 1686 MATH; 1936 MATH.

Augustus de Morgan publishes *Formal Logic*, which is partly symbolic but most notable for introducing the concept of quantification to logic. Quantification is the use of operators that mean “for all” or “there exists.” Operations with them had not been effective in

Aristotelian logic. Later mathematicians will show that logic with quantifiers is much more complex than the simple logic of propositions. *See also* 1858 MATH.

Medicine & health

Hungarian physician Ignaz Semmelweis discovers that puerperal fever (childbed fever) is contagious. He has doctors working for him wash their hands in the hopes of reducing the number of cases of the disease in his hospital, which proves to be effective if unpopular. *See also* 1843 MED; 1865 MED.

Charles Babbage invents the ophthalmoscope, the mirror with a hole in it that is used to examine the eye. *See also* 1851 MED.

Scottish physician James Eadsdale uses hypnosis for anesthetizing patients in surgery. *See also* 1841 MED; 1872 MED.

Karl Ludwig develops a device that continuously records blood pressure, which he uses to show that circulation of the blood is purely mechanical. No mysterious vital processes outside of ordinary physics need to be invoked. *See also* 1733 MED; 1863 MED.

Physics

Über die Erhaltung der Kraft (“on the conservation of energy”) by Hermann von Helmholtz independently provides a clear statement of the law of conservation of energy, previously stated by Robert Mayer in a little-read paper. *See also* 1842 PHY; 1850 PHY.

John William Draper shows that all substances begin to glow a dull red at about 525°C and that they progressively



Ignaz Philipp Semmelweis

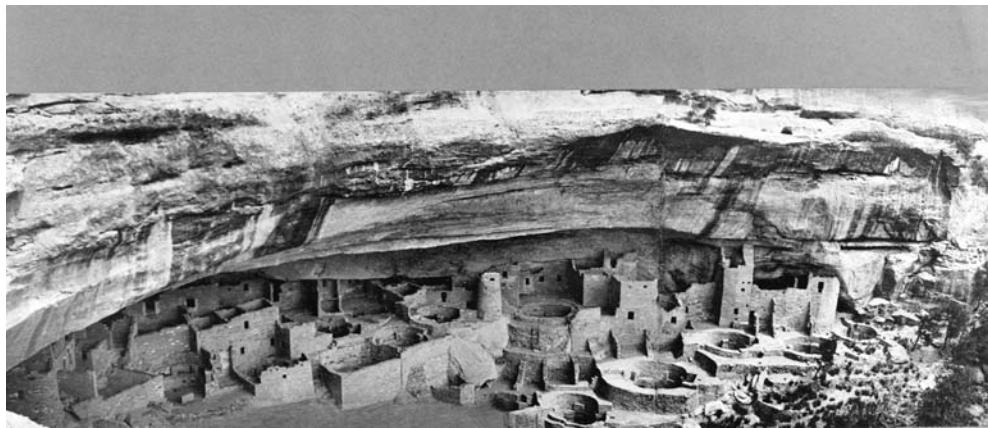
[b. Budapest, Hungary, July 1, 1818, d. Vienna, Austria, August 13, 1865]

Semmelweis noticed that deaths from puerperal fever were much more numerous among women attended by doctors and medical students than among women attended by midwives. In the mid-19th century it was common for a doctor to move directly from one patient to the next without washing his hands, or to move from performing an autopsy on a diseased body to examining a living person. Semmelweis hypothesized that “particles” introduced into the women caused puerperal fever, and that these particles were spread on the hands of the doctors and students. Semmelweis ordered that hands be washed in a chlorine solution before each examination. Mortality rates among women attended by doctors and medical students quickly dropped from 18.27 to 1.27 percent. In 1861 Semmelweis published a book that described his findings and recommendations. He influenced Joseph Lister but years passed before the importance of disinfection was widely appreciated.

change color as the temperature is raised, eventually reaching a bright white. *See also* 1893 PHY.

Tools

Matthew Townsend of Leicestershire, England, about this time invents the second form of knitting needle, the latch needle. *See also* 1589 TOOL.



MESA VERDE Some 600 elaborate stone "cliff dwellings," partly sheltered by the wall of the canyon, at Mesa Verde in southwestern Colorado were built by the ancestors of the Pueblo Native Americans about 1200 CE. A drought that started in 1276 is thought to have forced the ancestors of the Pueblos to leave the Mesa Verde region. The ruins were first entered by Europeans in 1874 but serious exploration started in 1888. The site has been a National Park since 1906.

1848

■ Archaeology

Lieutenant J.H. Simpson observes the cliff houses of Mesa Verde (Colorado) from a distance, but does not investigate. *See also* 1874 ARCH.

Guatemalan administrators Modesto Méndez and Ambrosio Tut are the first outsiders to call attention to the Maya ruins at Tikal, known in previous centuries only to the local Maya. *See also* 1841 ARCH.

★ Astronomy

George Phillips Bond [b. Dorchester, Massachusetts, May 20, 1825, d. Cambridge, Massachusetts, February 17, 1865] and his father William Cranch Bond discover the eighth moon of Saturn, Hyperion. It is also found independently later in the year by William Lassell. *See also* 1846 AST.

Julius Mayer calculates that the Sun would cool down in 5000 years in the absence of

an energy source and proposes that the solar surface is continuously struck by meteorites that heat it up. The problem of how the Sun remains hot persists until the recognition that nuclear fusion is the source of the energy of stars. *See also* 1854 AST.

Joseph Henry projects the Sun's image onto a screen and establishes that sunspots are cooler than the surrounding surface. *See also* 1852 EAR.

■ Biology

Physiologist Claude Bernard [b. Saint-Julien, Rhône, France, July 12, 1813, d. Paris, February 10, 1878] discovers that the liver makes and secretes glucose as the body's main energy supply. *See also* 1857 MED.

Richard Owen's *On the Archetype and Homologies of the Vertebrate Skeleton* proposes that the vertebra of different animals are modified to form skulls and other parts of the body. Although this theory is

incorrect, later biologists will recognize that the same basic bone structure may have very different roles in different vertebrates. *See also* 1871 BIO.

□ Chemistry

Two chemically identical forms of tartaric acid create a puzzle — natural acid from organic sources bends light but a synthetic version does not. Louis Pasteur uses a slight difference in the shapes of tartaric acid crystals as seen under a microscope to separate synthetic tartaric acid into a form that bends light to the right and a form that bends light to the left, founding the field of stereochemistry. The two forms, or isomers, are mixed in synthetic tartaric acid, canceling out the interaction with light. *See also* 1830 CHEM; 1858 CHEM.

□ Communication

Maria Mitchell is the first woman elected to join the American Academy of Science. *See also* 1847 AST.



Louis Pasteur

[b. Dôle, France, December 27, 1822, d. near Sevres, France, September 28, 1895]

In the 1850s, Pasteur was asked to study why products of fermentation, such as wine and beer, sometimes sour during production. He soon demonstrated that a specific microscopic organism causes each kind of fermentation, and that when other microorganisms get into the liquid, they can cause souring. He also showed that "germs" cause milk to sour and cause infectious diseases. Pasteur found that he could kill many microorganisms in wine by heating and then rapidly cooling the wine — a process now called pasteurization. While developing methods for culturing microorganisms in special liquid broths, Pasteur discovered that some microorganisms require air — specifically, oxygen — while others are active only in the absence of oxygen. He called these, respectively, aerobic and anaerobic organisms. In 1877 Pasteur began to study anthrax, a disease mainly of cattle and sheep. He developed a vaccine using a weakened strain of the anthrax bacterium. In 1885 he developed the first vaccination against rabies in humans.

■ Construction

Charles Ellet, Jr. builds the suspension bridge footpath over the Niagara River. *See also* 1842 CONS; 1849 CONS.

♥ Medicine & health

Rudolf Virchow coins the term *thrombosis* for the formation of blood clots and *embolus* for a blood clot that may detach and block blood vessels.

* Physics

William Thomson (Lord Kelvin), inspired by a suggestion of James Prescott Joule, proposes the concept of absolute zero, a temperature that is the least possible because, according to Charles's law, the volume of a gas would be zero at a temperature of -273°C (-460°F). Thomson suggests that the energy of molecules would be zero instead of the volume. *See also* 1787 PHY; 1852 CHEM.

Armand Fizeau suggests that light from a source moving away from the observer will be shifted toward the red end of the spectrum, a phenomenon known as redshift. This is essentially the same as the Doppler effect for sound. *See also* 1842 PHY; 1868 AST.

I Tools

Linus Yale Jr. [b. Salisbury, New York, April 4, 1821, d. New York, December 25, 1868] patents a lock based on pins in a rotating cylinder, the most common type in use today and still known as the Yale lock. *See also* 1818 TOOL.

1849

▲ Archaeology

Karl Richard Lepsius publishes *Chronologie der Aegypter* ("Egyptian chronology"), establishing the time frame of Egyptian antiquities. *See also* 1842 ARCH; 1850 ARCH.

★ Astronomy

Léon Foucault observes a resemblance between the sodium, or D, line in the solar spectrum and a line produced by an electric arc. He arranges to place the two spectra adjacent to each other and

observes that the lines are indeed in the same place. The main difference is that the line from the solar spectrum is dark, while the line from the electric arc is bright. *See also* 1843 AST; 1859 AST.

Edouard Albert Roche [b. Montpellier, France, October 17, 1820, d. Montpellier, April 18, 1883] develops the concept of Roche's limit — within two and one half times the radius of a planet a satellite would tend to break up into small particles. This rule suggests why Saturn's rings could not form into a moon, since they are within Roche's limit. *See also* 1848 AST; 1857 AST.

▲ Biology

Rudolf von Kölliker shows that nerve fibers are extensions of nerve cells. *See also* 1842 MED.

Arnold A. Berthold [b. 1803, d. 1861] of Göttingen, Germany, demonstrates the effect of hormones by showing that an extract from the testes or implantation of testes on castrated roosters prevents the appearance of signs of castration, such as loss of the comb. *See also* 1855 MED.

▲ Construction

Joseph Paxton builds a greenhouse to contain the Victoria Regia (now *Victoria amazonica*) Lily. The Victoria Regia Lily House is the first building to use the ridge-and-furrow construction with a flat roof and the first building to have a glass curtain wall hung from the girders. Both features, the second in a modified form, will be used in the Crystal Palace, which Paxton will begin to build the following year. *See also* 1841 CONS; 1851 CONS.

Charles Ellet, Jr. builds a 303-m (1010-ft) suspension bridge over the Ohio, one of the first major suspension bridges in the United States. It opens on November 15. *See also* 1848 CONS; 1855 CONS.

⊕ Earth science

Henry Clifton Sorby [b. Woodbourne, England, May 10, 1826, d. March 9, 1908] pioneers the use of a microscope to study thin slices cut from rock (called a petrographic microscope), an important technique that advances geology. Over the next 50 years he uses the technique to establish the true origins of sandstone, limestone, and other rocks.

▼ Energy

James Bicheno Francis [b. Southleigh, England, May 18, 1815, d. Lowell, Massachusetts, September 18, 1892] develops the inward-flow turbine (also known as the Francis turbine), in which water flows inward along a radius and emerges near the shaft, a highly efficient form still widely used for power generation. *See also* 1831 ENER.

George Henry Corliss [b. Easton, New York, June 2, 1817, d. February 21, 1888] patents an efficient steam engine that uses four valves instead of one. Each end of the cylinder has a spring-loaded inlet and exhaust valves, thus saving heat by regulating the amount of steam admitted. The Corliss-valve engine is considered the most significant advance in steam engine design since James Watt's. *See also* 1783 ENER.

■ Food & agriculture

The first blossom in England

of the gigantic (more than 30 cm, or 1 ft across) Victoria Regia (*Victoria amazonica*) water lily is presented to Queen Victoria, for whom it was named. The South American lily, first noted to science in 1801 and rediscovered about 1830, is grown in a specially built house by gardener James Paxton on the estate of the Duke of Devonshire. After opening twice, the flower sinks below the surface and produces edible seeds, known as *maiz del agua* (water maize). *See also* 1849 CONS.

♥ Medicine & health

Thomas Addison [b. Longbenton, England, April 1793, d. Bristol, England, June 29, 1860], in an article about anemia, reports that the adrenal glands are necessary for life, founding modern endocrinology. *See also* 1855 MED.

* Physics

William Thomson (Lord Kelvin) coins the term *thermodynamics* in an account of Nicolas Carnot's theory of heat. *See also* 1824 ENER.

Engineer James Thomson [b. February 16, 1822, d. 1892] predicts that applying pressure to water lowers its freezing point, using Nicolas Carnot's theory of heat.

Armand Fizeau measures the velocity of light in air by measuring the time it takes for a beam of light to pass between the teeth of a rotating gear, to be reflected by a mirror and be stopped by the next tooth of the gear. The result, 315,000 km/sec (196,000 mi/sec) is within 5 percent of today's accepted value. *See also* 1675 PHY; 1850 PHY.

I Tools

In a famous event in the annals of invention, on April 10 Walter Hunt of New York, New York, patents the safety pin (complete with spring closing) and assigns the rights to one Wm. or Jno. Richardson, the artist who made the patent drawings. It seems that Hunt owed money to the illustrator for past patent drawings and promised to assign him, in return for forgiveness of the debt and an additional \$400, the patent to any invention Hunt could make out of an old piece of wire. After about three hours of twisting the wire, Hunt comes up with the safety pin. *See also* 1842 TOOL.

Claude Étienne Minié, a captain of the French army, combines the work of several other innovators of the early 19th century to develop a cylindrical projectile for small arms that we now recognize as “bullet-shaped.” Nicknamed the Minnie Ball in English, versions of it are soon adopted by armies and hunters around the world.

Eugène Bourdon [b. Paris, April 8, 1808, d. Paris, September 29, 1884] patents a “metallic manometer.” It is a pressure gauge consisting of a curved tube closed at one end that is linked with a pinion rack to a pointer. When pressure is applied, the tube straightens and moves the pointer. The Bourdon gauge is still the most used pressure gauge in industry.

✈ Transportation

A manually operated block-signaling system is introduced by the New York & Erie Railroads. If a train is on a section

of track, no other train is allowed on that section. *See also* 1855 TRAN.

The first bombing raid from the air occurs when a pilotless Montgolfier balloon is used to drop bombs on Venice (Italy). *See also* 1783 TRAN.

1850

▲ Archaeology

Ephraim George Squier reports on his discovery of mysterious statues on islands in Lake Nicaragua in Central America that do not resemble the art of the nearby Maya. Later archaeologists relate the statues to art from the northern part of South America created by a group called the Chorotega.

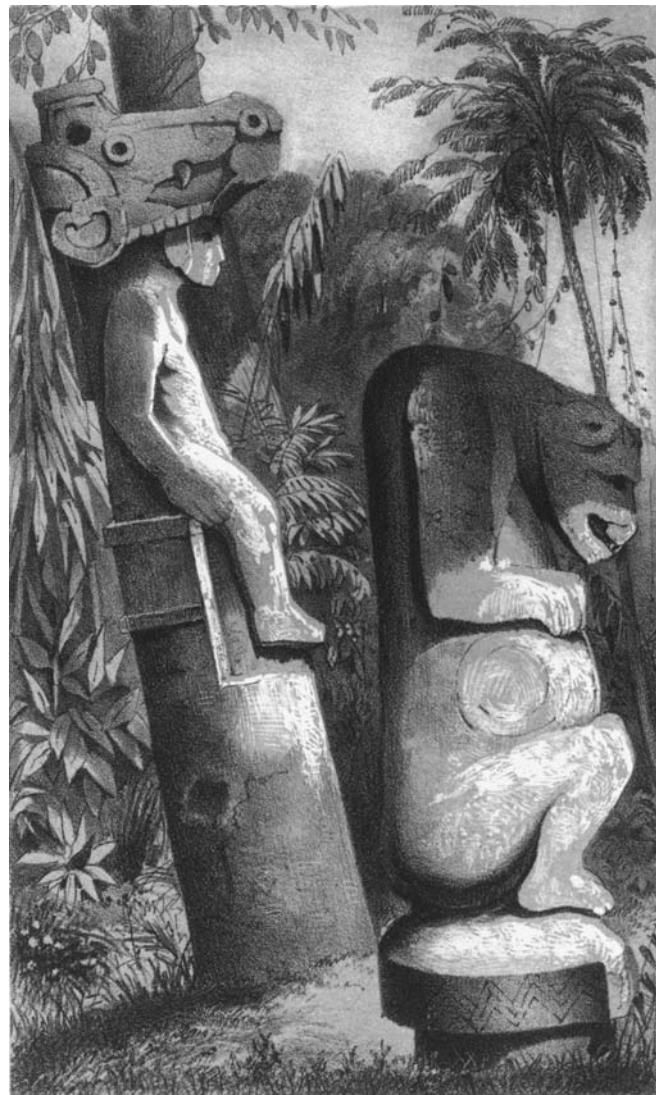
Auguste Mariette [b. Boulogne, France, 1821, d. Cairo, Egypt, 1881] arrives in Egypt and begins a program of surveying and excavation that leads him to locate the burial places of the sacred Apis bulls in Saqqara, the necropolis of Memphis, an early capital of Egypt. *See also* 1849 ARCH; 1851 ARCH.

★ Astronomy

William Parsons (Lord Rosse) reports that some nebulae (now recognized as galaxies) have a spiral structure. *See also* 1845 AST.

William Cranch Bond and John Adams Whipple take the first daguerreotype of a star, Vega, on the night of July 16–17. About this time, also, they make excellent daguerreotypes of the Moon. *See also* 1840 AST.

William Cranch Bond and George Bond rediscover the Crêpe ring or C ring of Saturn



CHOROTEGAN STATUES Ephraim George Squier, hearing of *piedras antiques* (“ancient stones”) in Nicaragua while he was the U.S. chargés d’affaires in neighboring Guatemala, found these strange statues and others like them on islands. These statues are from the island of Zapatero. While Squier investigated the archaeology of Nicaragua, he also studied the nation as a possible site for a Central American canal; but the volcanoes of Nicaragua persuaded the United States to build in Panama instead.

inside the B ring. *See also* 1838 AST; 1857 AST.

❖ Biology

German botanist Ferdinand Julius Cohn [b. Breslau (Wrocław, Poland), January 24,

1828, d. Breslau, June 25, 1898] shows that plant and animal cytoplasm are essentially the same substance. *See also* 1846 BIO; 1851 BIO.

Gustav Theodor Fechner discovers that an increase in the

intensity of a stimulus does not produce a one-to-one increase in the intensity of sensation. The sensation increases as the logarithm of the excitation. *See also* 1838 MED.

Chemistry

Thomas Graham distinguishes between crystalloids and colloids, founding the science of colloidal chemistry. As part of this work he also discovers dialysis. *See also* 1869 PHY.

Communication

Oliver T. Eddy [b. Greenbush, Vermont, 1799, d. Philadelphia, 1868] of Baltimore, Maryland, patents a typewriter that uses a piano keyboard to input letters. It is the first typewriter to use an inked ribbon instead of a roller or pad to supply the ink. *See also* 1843 COMM.

The firm of Siemens & Halske lays the first submarine telegraph cable, from Dover, England, to Calais, France. However, the cable is cut by the anchor of a French fishing boat. A new cable will be laid the next year. *See also* 1847 ENER.

Francis Galton [b. Birmingham, England, February 16, 1822, d. Haslemere, England, January 17, 1911] invents a teletype printer. *See also* 1872 COMM.

Construction

When the 500-year-old arched dam near Kurit (Iran) is raised by 4 m (13 ft) it becomes the highest dam until early in the 20th century. *See also* 1350 CONS; 1983 CONS.

Earth science

Oceanographer Matthew Fontaine Maury [b. near Fredericksburg, Virginia, 1806, d.

Lexington, Virginia, February 1, 1873] prepares a chart of the Atlantic Ocean and notes for the first time that it is shallower in the center than it is near the edges, the first indication of the mid-Atlantic ridge. *See also* 1925 EAR.

Energy

On February 18 Rudolf Clausius reads his paper *Über die bewegende Kraft der Wärme* ("on the driving power of heat") to the Berlin Academy. It is the first clear statement of the second law of thermodynamics, which is that energy in a closed system will change toward heat and disorder. The book supplies the theoretical foundation of steam engines. *See also* 1834 PHY; 1865 PHY.

Edward G. Shepard is the first to make an incandescent lamp using charcoal, while Sir Joseph Wilson Swan, English physicist and chemist [b. Sunderland, England, October 31, 1828, knighted 1904, d. Warlingham, England, May 27, 1914] begins to work with carbon filaments (made from paper). *See also* 1846 ENER; 1854 ENER.

Food & agriculture

Jean-Baptiste Boussingault [b. Paris, February 2, 1802, d. Paris, May 12, 1887] shows that plants absorb carbon from the atmosphere but obtain needed nitrogen from the soil. *See also* 1886 FOOD.

Cable plowing is introduced about this time; a stationary engine pulls a cable that draws the plow across the field.

Materials

James Young [b. Glasgow, Scotland, July 13, 1811, d. Edinburgh, May 14, 1883] this year or the following one produces



Rudolf J. E. Clausius

[b. Köslin, Pomerania (Poland), January 2, 1822, d. Bonn, Germany, August 24, 1888]

Clausius continued the work on thermodynamics originated by Nicolas Sadi Carnot and in 1850 became the first to state the second law of thermodynamics, which resolved some difficulties in Carnot's theory. In 1865 Clausius introduced the term *entropy* to describe the distribution of heat in a system, restating the second law as "in a closed system, entropy always increases." Clausius also contributed to chemistry by correctly proposing in 1851 that an electric current passes through a solution because of ionization, although few believed him at the time.

by Bernhard Bolzano contains the first use of the word *set* in mathematics and deals with infinite sets as actual infinites (not simply potentials) in a manner made popular later by Georg Cantor and Richard Dedekind. However, Bolzano's work will be overlooked until after these later developments. *See also* 1831 MATH; 1872 MATH.

Russian mathematician Pafnuty Lvovich Tchebycheff [b. 1821, d. 1894] improves a result in the theory of prime numbers in his paper "*Sur les nombres premiers*" ("on prime numbers"), setting limits on the value of the ratio of the number of primes less than a given number to that same number divided by its natural logarithm. Several earlier mathematicians had surmised that this ratio has 1 as a limit, but could not prove it. Tchebycheff reduces the possible range of the limit to between 0.922 and 1.105. He also proves that there is always at least one prime number between n and $2n - 2$ for $n > 3$ (known as Bertrand's conjecture). *See also* 1876 MATH.

The hydrocarbon wax paraffin is developed and used in candles as well as for sealing, in waxed paper, and as a lubricant.

the first distilled coal oil. *See also* 1739 ENER; 1855 MATR.

The beehive method of making coke from coal in small quantities replaces earlier methods, even though it wastes a great deal of coal, mainly because of the high-quality coke it produces. *See also* 1841 MATR; 1858 MATR.

About his time the modern age of adhesives begins with the invention of rubber cement.

Mathematics

Paradoxien des Unendlichen ("paradoxes of the infinite")

James Joseph Sylvester [b. London, September 3, 1814, d. London, March 15, 1897] introduces the concept of matrix in his paper "On a New Class of Theorems." A matrix is an array of numbers that can be treated as a single entity. *See also* 1858 MATH.

Medicine & health

Physician Carl Reinhold Wunderlich [b. Sulz (Germany), August 4, 1815, d. Leipzig, Germany, September 25, 1877] introduces the practice of taking accurate temperatures of patients with a thermometer as a regular part of

diagnosis. *See also* 1730 TOOL; 1866 MED.

❖ Physics

Léon Foucault, using rotating mirrors, observes that light travels slower in water than in air, a result that helps establish that light behaves as waves. Newton's particle theory of light predicts a faster speed in water than in air. *See also* 1849 PHY; 1851 PHY.

James Prescott Joule publishes the results of his experiments on heat and conservation of energy, stating the law of conservation of energy previously introduced by Robert Mayer and Hermann von Helmholtz. He claims that his version of the mechanical equivalent of heat, determined in careful experiments, supersedes Mayer's work. He also observes that heat and work are two different manifestations of energy. *See also* 1847 PHY; 1851 PHY.

I Tools

The power-driven combing machine for wool is introduced. *See also* 1789 TOOL.

Macedonio Melloni constructs a radiometer consisting of 100 thermocouples mounted in the form of a cube. *See also* 1820 TOOL; 1878 TOOL.

✈ Transportation

Pierre Jullien of Villejuif, France, builds and flies a cigar-shaped model airship in Paris. The longer of his two models is 15 m (49 ft) in length and is steered from the ground. Its two propellers are powered by clockwork and springs. All powered lighter-than-aircraft are termed "airships," while airships that can be steered are also termed "dirigibles," with both terms

usually interchangeable, so technically this is a dirigible. *See also* 1852 TRAN.

1851

▲ Archaeology

Auguste Mariette discovers and excavates the temple of Serapis and the tombs of Apis (an Egyptian god manifest as a bull) along with rows of sphinxes, jewels, and a mummy with a gold mask, using explosives that destroy some of the material being excavated. Mariette will complete the task in 1855. *See also* 1850 ARCH; 1857 ARCH.

★ Astronomy

Christian August Peters [b. 1806, d. 1880] calculates the orbit of Sirius B, the invisible (at this time) companion of Sirius, finding that it should have an orbital period of 50 years. *See also* 1844 AST; 1862 AST.

Sir Oliver Joseph Lodge [b. Staffordshire, England, June 12, 1851, d. Lake, Wiltshire, England, August 22, 1940] suggests correctly that the Sun may emit radio waves,

although these are not detected until the 1940s. *See also* 1942 AST.

❖ Biology

Wilhelm Hofmeister discovers the alternation of generations in such nonflowering plants as mosses and ferns. *See also* 1842 BIO.

Hugo von Mohl's *Grundzüge der Anatomie und Physiologie der vegetabilischen Zelle* ("principles of the anatomy and physiology of the vegetable cell") describes his view of the main contents of a cell (now called cytoplasm) and generally advances cell theory for plants, noting the fibrous structure of cell walls, for instance. *See also* 1850 BIO; 1861 BIO.

◆ Communication

The Great Exhibition of the Works of Industry of All Nations is held in London, opening on May 1. It features the latest technical innovations in industry and promotes the application of science to technology. *See also* 1851 CONS.

Frederick Scott Archer [b. Bishop's Stortford, England,

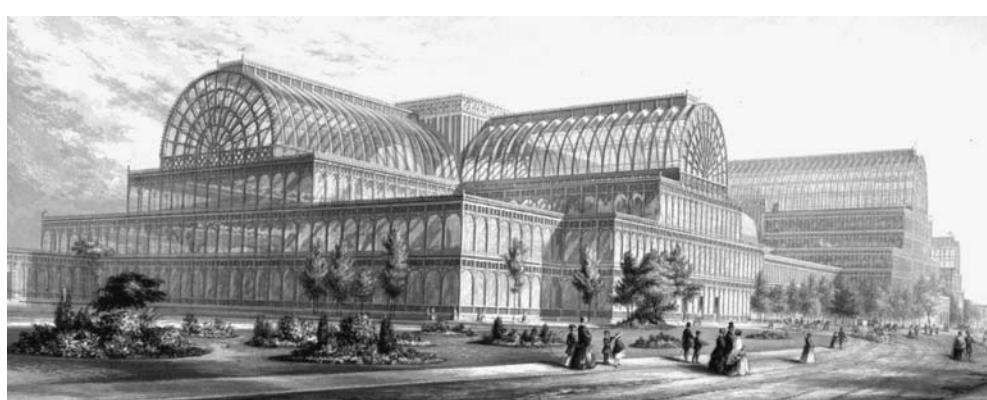
1813, d. London, May 2, 1857] introduces the wet collodion process, also called the calotype wet-plate process, to photography. He develops the idea of using a negative and making prints in photography. *See also* 1839 COMM; 1864 COMM.

London and Paris are linked by a submarine telegraph cable. An earlier attempt at laying a cable between Calais and Dover in 1850 failed when the cable was broken shortly after it had been laid. *See also* 1850 COMM; 1857 COMM.

■ Construction

The Crystal Palace, designed and built by Joseph Paxton, is opened on May 1 by Queen Victoria. A remarkable building of glass and iron, it is one of the highlights of the Great Exhibition in London. *See also* 1849 CONS.

William Channing and Moses Farmer [b. Boscowen, New Hampshire, February 9, 1820, d. Chicago, May 25, 1893] develop an electric fire alarm system in Boston. *See also* 1866 COMM.



THE CRYSTAL PALACE Paxton's Crystal Palace of 1851 became one of the most imitated buildings of all time. Versions of it, frequently called by the same name, appeared at other great national exhibitions, while the building was also the model for some of the earliest predecessors of today's shopping mall.

The Crystal Palace

Certain structures stand out in the history of architecture as the inspiration for whole schools of design and construction. Many of these, such as the Abbey Church of St. Denis, progenitor of the Gothic cathedral, continue to inspire to this day and are still physically available to students of architecture. None, however, has at the same time been so influential and so fleeting as the Crystal Palace of Joseph Paxton. Conceived between June 7 and July 26 in 1850, it was opened to the public on May 1, 1851, as the main building for the Great Exhibition of the Works of Industry of All Nations in London, an event often considered the first world's fair. After a highly successful run in Hyde Park at the Great Exhibition, the Crystal Palace was dismantled and re-erected two years later in south London, where it housed various exhibitions and events for another 72 years before being destroyed by fire. Nearly all of its architectural impact, however, came during its short stay at Hyde Park.

Paxton was primarily a gardener for large estates who had become involved in greenhouse design and construction. Many of the basic ideas for the giant Crystal Palace, which was as long as 18 football fields and as wide as 8, with another football-field wide addition on the side (9 times as long), came during the construction of much smaller greenhouses during the 20 years preceding. The two principal earlier greenhouses were erected for the duke of Devonshire at Chatsworth; they are important for their own sakes as well as for their influence on the Crystal Palace. The first, known as the Great Stove, was built between 1836 and 1841. Although a mere conservatory, the Great Stove actually had a span wider than that of London's familiar giant railway stations, which were built about the same time. The second Chatsworth building was a greenhouse designed to house a single plant, the giant Victoria Regia lily, which had been rediscovered by Europeans in 1832 and which the duke wished to bring to flower in England to present to the queen, for whom the plant had been named. (He succeeded in 1849, when Paxton's Victoria Regia Lily House was built; the plant produced 126 blooms during the following year.)

The Victoria Regia Lily House was, in some ways, a miniature Crystal Palace. Its main architectural features included a flat ridge-and-furrow roof and curtain-wall construction. The ridge-and-furrow roof, a series of sharp peaks and valleys, has not been much imitated, although the basic principles involved, such as a design that produces virtual beams, are still influential. Curtain walls, which were not used in their pure form in the Crystal Palace, became a hallmark of modern office construction, especially in the work of Mies van der Rohe. The curtain walls of the Victoria Regia Lily House were glass panes that hung from can-

tilevered girders. The hallmark of the curtain-wall system, introduced to modern office buildings in 1918, is that the outer skin of the building needs no supporting member. In the Crystal Palace itself the glass walls were hung but also supported by braces and columns.

The other architectural features of the Crystal Palace that came to influence modern architecture include the first system of portal bracing to counteract strong winds, needed because of the great size of the building; and the use of prefabricated modular units in construction, required to erect such a large building in just 17 weeks. As the Crystal Palace was the preeminent building of the Industrial Revolution, it is appropriate that it was also the first large freestanding building to use an iron frame (although much of the structure, including the columns framing the glass walls, was made from wood). The braces connecting columns to horizontal beams were iron, as were cross-braces used to strengthen the walls. The use of several different materials together in this way also became a hallmark of modern architecture. Finally, the Crystal Palace was among the first buildings to utilize prestressed members, in this case cast-iron beams.

Many of the statistics connected with the Crystal Palace remain astonishing today. It used 400 tons of glass, each 125-cm-sq (49-in.-sq) pane produced by blowing a cylinder, cutting it, and flattening it by reheating. With its modular construction, a team of 80 workers was able to install 18,932 panes in a week, resulting in a total surface array of glass of 85,000 m² (900,000 sq ft). The glass was supported by 3300 cast-iron columns and held in place by 330 km (205 mi) of wood sash.

Similar buildings were erected in 1852 in Dublin, in 1853 in New York City, and in 1854 in Munich, all to house, as the original had, exhibitions of new technology. Later in the century, many of the first department stores in France, England, and the United States took elements from the Crystal Palace in the way that they displayed their wares. Another series of imitators, some of which are still in use, were city shopping arcades or galleries, in many ways the predecessors of today's suburban malls. It was not until the 20th century, however, that the principles of the Crystal Palace came to be common in buildings designed to be occupied for work or for living quarters. The essence of all 19th-century versions of the idea was display.

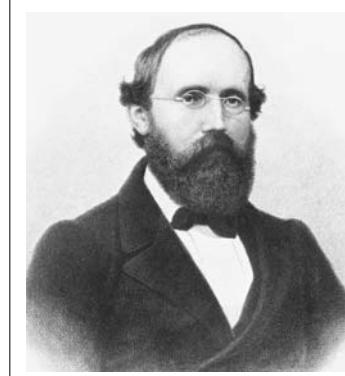
A barrier to erecting livable or workable versions of the Crystal Palace was that the Victorians, while they admired its utility and speed of construction, failed to recognize the architectural beauty of the building. It was just too strange. Architecture was still thought of primarily in terms of churches and great houses, built largely of stone. An insubstantial thing of glass, iron, and wood might serve a purpose, but no one would want to have such a giant greenhouse as an office and certainly not as a home.

❖ Materials

The first electrolytic process for the production of chlorine is patented in Great Britain by Charles Watt. *See also* 1838 MATR; 1858 MATR.

Σ Mathematics

Bernhard Riemann relates the theory of complex-number functions to the theory of n -dimensional surfaces in a complex domain, now called Riemann surfaces. That is, he gives a geometric interpretation to functions of z where z can be any complex number. *See also* 1843 MATH.



(Georg Friedrich) Bernhard Riemann

[b. Hanover, Germany, September 17, 1826, d. Selasca, Italy, July 20, 1866]

Riemann's work made mathematics more general or abstract. He put the definite integral on a firmer basis with a generalization now called the Riemann integral. In 1851 Riemann invented a new way to show functions of complex numbers on a plane and developed fundamental ideas of topology to handle such representations. In 1854 Riemann addressed the foundations of geometry in spaces of n dimensions, suggesting a new form of non-Euclidean geometry that later became the geometry of Einstein's general theory of relativity. In 1859 Riemann made a conjecture about a complex function called the zeta function that remains among the main unresolved issues of mathematics.

♥ Medicine & health

Claude Bernard discovers that nerves controlling the dilation of the blood vessels control the body's temperature in humans. *See also* 1850 MED.

Hermann von Helmholtz reinvents the ophthalmoscope independently of Charles Babbage's version of 1847. *See also* 1847 MED; 1911 MED.

❖ Physics

Léon Foucault uses a pendulum to demonstrate Earth's rotation. The plane of a 67-m (220-ft) pendulum in the Pantheon building in Paris that swings freely rotates exactly as calculated for Earth's rotation at the latitude of Paris. The plane of the swing would rotate with a period of 24 hours at the North Pole, but would not rotate at all at the equator. *See also* 1852 TRAN.

ally becomes uniform heat.
See also 1850 PHY.

Armand Fizeau shows that the velocity of light is higher in water flowing in the direction of the beam than that of light

propagating in the direction opposite the direction of flow.
See also 1850 PHY.

George Stokes develops the formula, now known as Stokes' law, that describes the velocity

of a small sphere falling through a viscous fluid, such as a heavy oil. *See also* 1842 PHY.

I Tools

Isaac Merrit Singer [b. Oswego, New York, October 27, 1811, d. Torquay, England, July 23, 1875] patents a continuous-stitch sewing machine. *See also* 1846 TOOL.

German physicist Heinrich Rühmkorff [b. Hanover (Germany), January 15, 1803, d. Paris, December 19, 1877] develops the induction coil, or spark inductor. An iron core is surrounded by two coils, one with a low number of windings and one with a very high number of windings. Quickly interrupting repeatedly a current in the first coil creates a very high voltage in the second coil. Induction coils have been used in experiments with gas discharge tubes, cathode-ray tubes, and X-rays. They also served as the first radio transmitters. *See also* 1889 COMM.

American James King develops a washing machine with a rotating drum.



A FOUCALUT'S PENDULUM The idea of a pendulum demonstrating the motion of Earth has proved popular as a physics demonstration in museums and public buildings of all kinds. The example shown here is a feature of the Science Building at Berea College in Kentucky.

→ Transportation

John Ericsson's ship *Ericsson* uses his then radical design

for a forerunner of the modern gas turbine, but Ericsson's engine is so heavy that the ship is slower than ships of the time with conventional steam engines. *See also* 1844 TRAN.

1852

★ Astronomy

Johann Rudolph Wolf [b. 1816, d. 1893] finds that the sunspot activity of the Sun varies with a period of 11 years. About this time a number of other scientists verify that there is a sunspot period of 10 or 11 years. *See also* 1843 AST.

↗ Biology

Hermann von Helmholtz becomes the first to discover how fast a message travels along a nerve, measuring the speed of transmission in a frog's nerve cell. *See also* 1891 BIO.

▷ Chemistry

Henri-Victor Regnault [b. Aix-la-Chapelle, France, July 21, 1810, d. Auteuil, France, January 19, 1878], independently of William Thomson (Lord Kelvin), shows that the behavior of gases deviates slightly from Boyle's law and determines absolute zero to be -273°C , although he does not have a clear idea of what the behavior of a gas at that temperature might be. *See also* 1848 PHY.

Edward Frankland introduces the concept of valence of elements into chemistry; that is, that each atom has a definite capacity to combine with a certain specific number of other atoms. That number is the valence. *See also* 1891 CHEM.

⊕ Earth science

Johann von Lamont discovers periodic variations of about 10.3 years in the magnetic field of Earth, but does not relate them to the occurrence of sunspots (even though he also knows of the sunspot cycle). *See also* 1828 EAR.

Sir Edward Sabine [b. Dublin, Ireland, October 14, 1788, d. Richmond, Surrey, June 26, 1883] shows that changes in sunspots induce parallel changes in Earth's magnetic field, the first recognition that sunspots might have something to do with magnetism. About this time Johann Rudolf Wolf in Germany and Alfrede Gautier in France also recognize that sunspot activity correlates with changes in Earth's magnetic field. *See also* 1848 AST.

↗ Energy

William Thomson (Lord Kelvin) describes the heat pump; heat is absorbed by the expansion of a working gas and given off at a higher temperature in a condenser. The air conditioner is an application of the heat-pump principle, since the pump will heat in one direction and cool in the other. *See also* 1930 ENER.

◊ Materials

William Kelly [b. Pittsburgh, Pennsylvania, August 21, 1811, d. Louisville, Kentucky, February 11, 1888], working in a small town near Eddyville, Kentucky, and aided by four Chinese steel-making experts, invents a new process for making steel that anticipates the Bessemer process, which will be invented only four years later. He fails to patent his ideas, however, until after learning of the

Bessemer process. *See also* 1856 MATR.

Σ Mathematics

Traité de géométrie supérieure ("treatise on higher geometry") by Michel Chasles [b. Epernon, France, November 15, 1793, d. Paris, December 18, 1880] uses synthetic methods (that is, geometric proof instead of algebra) to handle projective and other basic geometries. He introduces the concepts of cross-ratios, pencils, and involutes. His book is also influential in establishing the use of directed line segments in geometry. *See also* 1847 MATH.

♥ Medicine & health

Karl Vierordt [b. Lahr, Germany, July 1, 1818, d. Tübingen, Germany, November 22, 1884] makes the first accurate count of red blood cells, using a technique that later becomes an important tool for diagnosing anemia. *See also* 1855 MED.

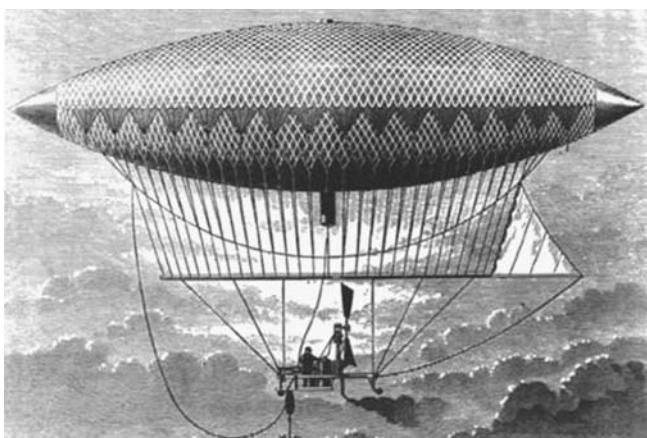
⊗ Physics

James Prescott Joule and William Thomson (Lord Kelvin) establish that an expanding gas becomes cooler, now known as the Joule-Thomson effect.

George Stokes names the phenomenon of fluorescence. *See also* 1857 ENER.

→ Transportation

Henri Giffard [b. Paris, 1825, d. 1882] builds and on September 24 flies a 44-m (144-ft) airship, powered by a steam engine of 2.2 kW (3 hp) driving a three-blade propeller 3.3 m (11 ft) in diameter at 110 rpm. He travels almost 27 km (17 mi) at about 10 km (6 mi) per hour. Later he will make a second flight, modifying the design somewhat for greater speed. *See also* 1783 TRAN; 1872 TRAN.



GIFFARD'S STEAM-POWERED AIRSHIP Henri Giffard's dirigible was really a ship of the air, with its backward facing propeller and centered stern rudder (although the passenger rode below both instead of atop the airship). The main problem on its first test flight was inadequate power to move the ship fast enough for the rudder to steer it in even light winds. Giffard added a second balloon to provide more support for a more powerful engine on the second flight, but leaking gas brought that flight to an abrupt halt. Although Giffard designed another airship with a larger balloon and a still more powerful engine, the plan was too expensive and that version was never built.

Léon Foucault names a freely spinning flywheel the *gyroscope*, inventing the basis of the modern toy by recognizing the tendency of the gyroscope to maintain its orientation as long as it is spinning. He uses a gyroscope to demonstrate the rotation of Earth and correctly predicts the use of the gyroscope as a compass. *See also* 1744 TRAN; 1908 TRAN.

Elisha Graves Otis [b. Halifax, Vermont, August 3, 1811, d. April 8, 1861] invents the first elevator that has a safety guard that keeps the elevator from falling even when the cable is completely cut. *See also* 1854 TRAN.

1853

Communication

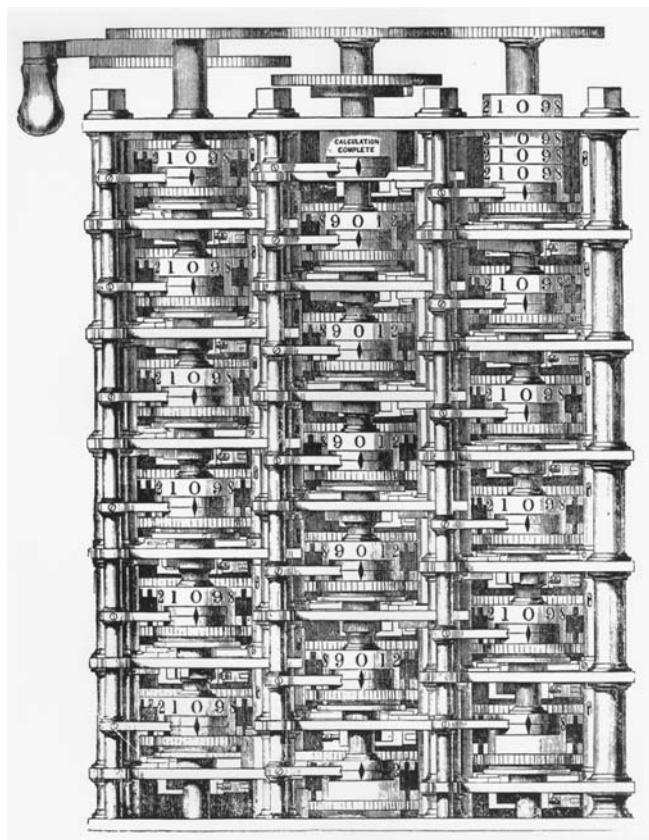
Josiah Latimer Clark [b. Great Marlow, England, March 10, 1822, d. London, October 30, 1898] builds a pneumatic system for sending telegrams between the London Stock Exchange and the International Telegraph Company's London office. Documents are placed in cylinders that are sucked through a tube 220 m (720 ft) long. *See also* 1858 COMM.

Computers

Pehr Georg Scheutz builds a working copy of Charles Babbage's Difference Engine and gives a demonstration of it at a London exhibition. *See also* 1843 COMP.

Construction

Pierre Carpentier invents corrugated steel plate, which will find a wide application in construction. *See also* 1832 CONS.



DRAWING OF BABBAGE'S DIFFERENCE ENGINE The Difference Engine was designed to calculate (and print) tables correct to 31 significant digits, much better than most modern calculators or even most computers. When finally assembled out of some 4000 machined parts on the basis of Babbage's drawing, the machine performed perfectly, although the crank had to be turned hundreds or thousands of times to finish the calculations. Mathematically the only operation performed was addition, but the machine could be programmed to use that single operation to calculate tables of values for any function.

Earth science

James Henry Coffin [b. Williamsburg, Massachusetts, September 6, 1806, d. Easton, Pennsylvania, February 6, 1873] describes three distinct wind zones that occur in the Northern Hemisphere. *See also* 1835 PHY.

Energy

The first attempts are made to use an electric generator (instead of a battery) to power an arc lamp. *See also* 1862 ENER.

Food & agriculture

According to legend, the potato chip is invented by Native American chef George Crum at Moon Lodge in Saratoga Springs, New York, while he is trying to imitate a guest's memory of fried potatoes from France.

Materials

Abraham Gesner [b. Cornwallis, Nova Scotia, May 2, 1797, d. Halifax, Nova Scotia, April 29, 1864], who first

made a flammable liquid (that he named kerosene) from oil shale in 1846 and later from coal, begins to manufacture kerosene from coal in New York State. Kerosene quickly replaces whale oil as the most popular illuminating liquid, but when kerosene is extracted from petroleum by Samuel Kier [b. Livermore, Pennsylvania, 1813, d. Pittsburgh, Pennsylvania, October 6, 1874], also starting in this year, Gesner's coal-based process loses out to the new form of kerosene. *See also* 1855 MATR.

Hans Peter Thomsen [b. Copenhagen, Denmark, February 16, 1826, d. Copenhagen, February 13, 1909] develops a method of producing sodium carbonate, an important industrial chemical sometimes called "soda" or "soda ash," from cryolite, an uncommon but useful mineral (sodium aluminum fluoride).

Mathematics

William Shanks [b. Corsenside, England, January 25, 1812, d. Houghton-le-Spring, Durham, England, 1882] completes his calculation of the value of π to 707 places. In 1944 it will be discovered, however, that his mistake in the 528th place caused all of the subsequent places to be incorrect.

Medicine & health

In Scotland Alexander Wood [b. 1817, d. 1884] invents the hypodermic syringe. A parallel invention in France is developed in Lyon about the same time by Charles Gabriel Pravaz [b. 1791, d. 1853].

The value of π

It is surprising, but many college students when asked which is greater, 3.14 or 22/7, will say that the two numbers are the same. That is because they think that both numbers are the same as the number π . Neither number is actually π . Since the decimal expansion of 22/7 starts off 3.1428571 . . . it is the greater number.

There is some evidence that the ancient Hebrews and Babylonians were even less accurate than today's college students. In the Bible (I Kings 7:23) we learn of the model of a sea made by Hiram of Tyre for King Solomon: "it was round, ten cubits from brim to brim, and a line of thirty cubits measured its circumference." The implication is that π is 3, since π is the ratio of the circumference of a circle to its diameter. There is some evidence that Babylonian mathematicians used a better value for π , namely 3.125.

It was clear to the ancient Greeks and Chinese that one could get a good approximation of π by comparing a circle to the straight-sided figure that is approximately a circle, a regular polygon with many sides. It is relatively easy to find the length of the perimeter of such a regular polygon if you know the distance from the polygon's center to one of its sides or to one of its vertices. Using this method, Archimedes calculated that π is between $3\frac{10}{71}$ and $3\frac{10}{70}$ (22/7), while Chinese scholars around 500 CE showed that π is between 3.1415927 and 3.1415926. In 1596 Ludolph of Cologne used this method to calculate π to 32 places. His result was engraved on his tombstone and to this day Germans call π the Ludolphine number.

Although everyone knew that these values for π were not exact (since they were based on perimeters of polygons, not the circumference of a circle), it was not clear whether an exact value could be found. Around the time of Ludolph, the algebraist Vieta developed the first simple numerical expression for π . It was not expressed as a decimal numeral or as a fraction, however. It was an infinite product. Later mathematicians also found other infinite products and infinite series (sums) for π . Two with especially easy patterns are actually for $\pi/2$ and $\pi/4$. In the 17th century John Wallis discovered $\pi/2 = 2/1 \times 2/3 \times 4/3 \times 4/5 \times 6/5 \times 6/7 \times \dots$; in which the numerators are the even numbers from 2 given twice, while the denominators are a similar pattern of odd numbers. James Gregory and Wilhelm Gottfried Leibniz discovered an even simpler pattern for an infinite sum: $\pi/4 = 1/1 - 1/3 + 1/5 - 1/7 + 1/9 - 1/11 + \dots$. This pattern is known as the Leibniz series, although Gregory was the first to find it. Note that these patterns carried to infinity yield exact values for π , but they still do

not tell whether π can be expressed as a finite decimal. Many infinite products and series converge to finite decimals.

These infinite products and series, and others like them, however, provided an easier way to compute approximations to π than using polygons. At the end of the 17th century, Abraham Sharp found 71 decimal places. In the 19th century, π was gradually extended, reaching 707 places in the calculation of William Shanks in 1853 that took him 15 years to complete. When computers were invented, however, it was found that Shanks had made a mistake in the 528th place, causing every place afterward to be wrong.

In the meantime, in the 18th century, Johann Lambert finally solved one of the problems connected with π . He showed that π is irrational; in other words, it cannot be expressed as a finite decimal, nor can it have a simple repeating pattern as a decimal.

A related problem was still unsolved. Since the time of Anaxagoras at least, in the fifth century BCE, people had been trying to use a straightedge and compass to construct a square the same area as a given circle. By 1775 the ranks of people trying to solve this famous problem were so great that the Academy of Paris passed a resolution that it could no longer examine purported successes.

This problem was effectively solved in 1882, when the mathematician Ferdinand Lindemann showed that π is a member of a large class of numbers of which only a few are commonly known. These numbers are called *transcendental*. There are more of them than of any of the more familiar numbers. Their defining characteristic is that they are not the solutions to algebraic equations with integer coefficients. Constructing a line with a straightedge and compass implies that its length is the solution to such an equation. Since π is transcendental, it cannot be that kind of solution. Squaring the circle is impossible.

This did not stop people from calculating the value of π to more and more decimal places. When electronic computers became available in the 1940s and 1950s, some people used the calculation of π as a kind of demonstration of how powerful these computers were. By 1949, in 70 hours of computer time (as opposed to Shanks's 15 years of paper-and-pencil time), π was extended to 2037 places. By 1988 Japanese computer scientist Yasumasa Kanada had reached 201,326,000 decimal places. The 1988 computation only took six hours of supercomputer time. In 2002 Kanada and fellow researchers at Japan's Information Technology Center set a new record for finding the number of digits of π — 1.24 trillion decimal places. This calculation took about 602 hours.

* Physics

Johann Wilhelm Hittorf [b. Bonn, Rhenish Prussia, March 27, 1824, d. Münster, Rhenish Prussia, November 28, 1914]

suggests that ions in a solution, when impelled by an electric current passing through the solution, travel at different rates depending on

the type of ion. *See also* 1833 PHY.

William John Macquorn Rankine [b. Edinburgh, Scotland, July 5, 1820, d. Glasgow,

December 24, 1872] introduces the concept of potential energy, or energy of position. *See also* 1856 PHY.

I Tools

Jean Jacques Farcot develops a system for the continuous control of the speed of steam engines, a regulator that keeps the rate steady for different speeds. *See also* 1863 TOOL.

✈ Transportation

Sir George Cayley's helicopter "toys" modeled on Chinese toy helicopters are shown to go 27 m (90 ft) into the air. *See also* 1843 TRAN; 1877 TRAN.

1854

▲ Archaeology

In Denmark Jens Jacob Worsaae is appointed professor of archaeology at the University of Copenhagen, the first academic post for an archaeologist. *See also* 1847 ARCH.

★ Astronomy

Hermann von Helmholtz proposes that the Sun is heated by gravitational contraction and calculates that if the Sun contracted by 60 m per year it would keep radiating for another 15,000,000 years. Furthermore, his calculations show that the Sun has existed for only 25,000,000 years, far too short a time (present estimates are 4,600,000,000 years). He also predicts the "heat death" of the universe: Because of the laws of thermodynamics, the universe will ultimately reach a state of uniform temperature. Under such conditions, stars cannot shine. *See also* 1848 AST.

▷ Chemistry

Experiments by David Alter [b. December 3, 1807, d. 1881] in Freeport, Pennsylvania, lead him to the conclusion that each element can be identified from its spectrum. *See also* 1859 AST.

Alexander William Williamson [b. London, May 1, 1824, d. May 6, 1904] is the first to explain how a catalyst works by forming an intermediate compound. *See also* 1888 CHEM.

⌚ Communication

Great Britain's postal services introduce stamps separated by perforated lines, dispensing with the need for scissors to separate them. *See also* 1840 COMM.

George Herman Babcock [b. Unadilla Forks, New York, June 17, 1832, d. Plainfield, New Jersey, December 16, 1893] and his father develop the polychromatic printing press. *See also* 1818 COMM; 1858 COMM.

💻 Computers

George Boole publishes *An Investigation of the Laws of Thought, On Which Are Founded the Mathematical Theories of Logic and Probabilities*, which continues Boole's development of the first form of symbolic logic, known today as Boolean algebra. *See also* 1847 MATH; 1867 COMP.

㊀ Earth science

Sir George Biddel Airy [b. Alnwick, England, July 27, 1801, d. Greenwich, England, January 2, 1892] measures the mass of Earth by timing a pendulum at the top and bottom of a coal mine. From the difference he could compute the variation in the force of gravity and work backwards from that to Earth's density. *See also* 1798 PHY.

Heinrich Ernst Beyrich [b. Berlin, August 31, 1815, d. April 9, 1896] identifies the Oligocene period in Earth's history. *See also* 1841 EAR.

⚡ Energy

Heinrich Göbel, a German watchmaker who had emigrated to New York, constructs an incandescent electric lamp with a filament of carbonized bamboo placed in a glass vessel. In 1893 he wins a court case against Thomas Edison and receives credit as the inventor of the electric lamp. *See also* 1850 ENER; 1879 ENER.

Daniel Halladay produces the first U.S. windmills, modeled on European devices but with wooden instead of cloth sails. *See also* 1759 ENER.

Σ Mathematics

Karl Weierstrass [b. Ostenfelde, Westphalia (Germany), October 31, 1815, d. Berlin, February 19, 1897] publishes *Zur Theorie der Abelschen Functionen* ("on the theory of Abelian functions"), which earns him instant recognition in the mathematical community. *See also* 1825 MATH.

Bernhard Riemann's *Über die Hypothesen welche der Geometrie zu Grunde liegen* ("on the hypotheses that underlie the foundation of geometry") generalizes the concept of non-Euclidean geometry to show that various non-Euclidean geometries are possible (delivered as a lecture June 10, not published until 1868). Riemann demonstrates a logical geometry that has a different version of the parallel postulate from earlier versions of non-Euclidean geometry. *See also* 1832 MATH; 1868 MATH.

Bernhard Riemann proposes a definition of the integral that does not require the function being integrated to be continuous. *See also* 1902 MATH.

Geologist William Kennett

Loftus finds two clay tablets in Babylonian that show that Mesopotamian peoples used a place-value system of numeration based on 60. *See also* 1820 MATH.

♥ Medicine & health

John Snow [b. York, England, March 15, 1813, d. London, June 16, 1858] shows that removing the pump handle of a well contaminated by sewage reduces the incidence of cholera in the vicinity of the well. *See also* 1844 MED; 1866 MED.

✈ Transportation

In May Elisha Otis demonstrates his safe and workable freight elevator (lift) at New York's Crystal Palace. *See also* 1852 TRAN; 1857 TRAN.

1855

↗ Biology

Rudolph Virchow states "omnis cellula a cellula" (all cells arise from cells); that is, all cells are produced by pre-existing cells. *See also* 1846 BIO; 1858 MED.

▷ Chemistry

Charles Adolphe Wurtz [b. Wolfisheim, Alsace, France, November 26, 1817, d. Paris, May 12, 1884] develops the method of synthesizing long-chain hydrocarbons using hydrocarbon iodides and sodium, a method still known as the Wurtz reaction.

About this time Robert Bunsen begins using the gas burner that is named for him. Bunsen is not the inventor, however, for the burners he uses were developed by his technician, Peter Desaga. Furthermore, essentially the same type of burner was developed earlier by Michael Faraday.

The cell theory

Before the 19th century, when people thought of the structure of living organisms, they recognized tissues and organs but assumed that the tissues were simple substances similar to nonliving materials. They did not expect a level of organization between simple substances and recognizable tissues. Even when early microscopist Robert Hooke observed and named cells (because they looked like the cells in a monastery) in 1665, he did not realize that he was making a fundamental discovery about life.

Plant cells are easier to see through a microscope than animal cells because plants have cell walls and animals do not. As microscopes continued to improve, scientists observed cells in various plant tissues. Even so, as late as 1831, when Robert Brown first noted that plant cells all contain a small dark body that he named the nucleus ("little nut"), there was no recognition of the importance of cells. In 1835 Johannes Purkinje noted that animal tissues are also made of cells, but this observation attracted little attention.

This all changed suddenly in 1838 when Matthias Schleiden proposed that all plant tissues are made from cells. The following year, Theodor Schwann proposed that eggs are cells and that all

animal tissues are also made from cells. Schwann suggested that all life starts as a single cell. Thus the cell theory is generally attributed to Schleiden and Schwann, since each contributed vital parts to the theory.

Schleiden and Schwann were right about the basic idea of the cell theory, but other workers had to correct the details and extend the theory. For example, Schleiden thought that new cells are formed as buds on the surfaces of existing cells. Karl Wilhelm von Nägeli showed that this is not true — they form by division on one cell into two, although it took many years before cell division was fairly well understood. In 1845 Karl Theodor Ernst von Siebold extended the cell theory to protists, single-celled creatures. He thought, however, that multicellular organisms are made from protists. Rudolf Albert von Kölliker demonstrated in the 1840s that sperm are cells and that nerve fibers are parts of cells.

The cell theory was promoted by Rudolph Carl Virchow in the 1850s. His credo was "all cells arise from cells." Virchow also suggested that disease is caused when cells revolt against the organism of which they are a part. While this might be one way to view cancer, Virchow regarded all forms of disease this way, which caused him to resist Pasteur's germ theory. Despite such occasional setbacks, the cell theory became one of the main foundations of modern biology.

Communication

William Thomson (Lord Kelvin) develops a theory of transmission of electrical signals through submarine cables that is applied to the first submarine telegraph cables. *See also* 1851 COMM; 1857 COMM.

French chemist Alphonse-Louis Poitevin [b. Sarthe, France, 1819, d. Sarthe, March 4, 1882] invents a printing process called collotype that reproduces photographs much more accurately than most other methods of printing pictures. Similar in some ways to offset lithography, collotype is difficult to use and most suitable for very short print runs. *See also* 1798 COMM; 1858 COMM.

In London Giuseppe Devincenzi patents the first known electric writing machine, almost 50 years before the first

successful electric typewriter. *See also* 1872 COMM.

Computers

A version of the Babbage Difference Engine built by Swedish engineer Pehr Georg Scheutz and his son Edward is awarded a Gold Medal at the Paris Exposition. *See also* 1834 COMP.

Construction

John Augustus Roebling completes the Niagara River Suspension Bridge for railroad travel. The 250-m (821-ft) span uses only one-fourth as much material as the 140-m (460-ft) span of the Britannia rail bridge over the Menai Strait in North Wales. *See also* 1825 CONS.

Earth science

Luigi Palmieri [b. Faicchio (Italy), April 22, 1807, d.

Naples, September 9, 1896] invents the first crude seismometer of modern times to measure the size and location of earthquakes. *See also* 132 CE EAR; 1880 EAR.

Matthew Maury's *Physical Geography of the Sea* is the first textbook of oceanography. *See also* 1868 BIO.

Energy

The safety match is invented in Sweden. Such a match will light only when struck on a chemically impregnated surface. Previous friction matches would light when struck on any rough surface. *See also* 1830 ENER.

Materials

Henri-Etienne Sainte-Claire Deville [b. St. Thomas, Virgin Islands, March 11, 1818, d. Boulogne-sur-Seine, France,

July 1, 1881] develops a new method of producing aluminum and casts a 7-kg (15-lb) ingot. Over the next four years the price of aluminum is reduced by a factor of 100, although it is still more expensive than steel. *See also* 1825 CHEM; 1886 MATR.

French chemist George Aude-mars develops a process for making fibers from cellulose, but cannot produce the fiber in commercial quantities. This is accomplished by the same process about 30 years later. *See also* 1834 CHEM; 1884 MATR.

F. Köller develops a type of steel that contains tungsten. *See also* 1883 MATR.

Benjamin Silliman obtains several products by distilling oil, such as tar, naphthalene, gasoline, and solvents. *See also* 1853 MATR; 1859 MATR.

Alexander Parkes, English chemist [b. Birmingham, England, December 29, 1813, d. London, June 29, 1890], obtains a patent in England on parkesine, a substance resembling collodion that he has developed by mixing anhydrous wood alcohol with gun cotton. *See also* 1846 MATR; 1862 MATR.

♥ Medicine & health

Thomas Addison describes the hormone deficiency disease that results from deterioration of the adrenal gland (Addison's disease). He also is the first to describe pernicious anemia, a disease recognized today as caused by a deficiency of vitamin B₁₂. *See also* 1849 MED; 1885 MED.

Claude Bernard's *Leçons de physiologie expérimentale* ("lessons in experimental psychology") advances his theories of homeostasis in the body, the concept that the body maintains a constant environment even though external conditions change.

Robert Arthur introduces the technique of filling teeth with gold foil, heating the foil to rid the surface of impurities and then cold-welding it in the cavity with pressure from instruments. *See also* 1450 MED.

⌘ Physics

Heinrich Geissler, [b. Igelshieb (Germany), May 26, 1814, d. Bonn, Germany, January 24, 1879] invents his mercury pump, which he uses to produce the first good vacuum tubes. These tubes, as modified by William Crookes, become the first to produce cathode rays, initiating our understanding of the electron. *See also* 1838 PHY; 1876 PHY.



Sir William Crookes
[b. London, June 17, 1832, d. London, April 4, 1919]

William Crookes trained as a chemist but became interested in spectrometry and electrical discharges into near vacuums; his major discoveries emerged from these interests. In 1861 he recognized that a green line on a spectrogram must be a new element; he isolated the element and named it thallium. In 1875 he invented the radiometer, an evacuated transparent bulb that has an arrangement of vanes, black on one side and silvered on the other, that spins when placed in a light (the cause is unequal heating of the gases left in the bulb near the black and the silver vanes). Crookes's name is preserved in his vacuum tubes. He did not invent the vacuum tube with a cathode and anode to produce an electric current, but his Crookes tubes were superior. With them he discovered the basic properties of the electric discharge, or cathode ray, from which J.J. Thomson was to discover the electron, confirming Crookes's own views on the nature of cathode rays.

I Tools

Alexander Thophilus Blakely patents in Britain a method for building cannon barrels from hoops of iron. This method, subsequently adopted in all cannon manufacture, is developed around the same time in the United States and also by other British manufacturers, but Blakely demonstrates the superiority of his design mathematically and shows how it can be systematically accomplished. *See also* 1774 TOOL.

The turret lathe is invented in the United States. Different tools are mounted on a revolving drum, called the turret head.

➔ Transportation

Vignier, working for the Compagnie de l'Ouest, links the signals of a block-signaling system for railroad trains with switches, making errors in switching impossible when the signals are correct. *See also* 1849 TRAN; 1867 TRAN.

1856

◀ Anthropology

A skeleton is found in a cave in the Neander valley near Düsseldorf, Germany. Although derided by many as recent, it is actually the first known remains of what we now call the Neandertals (a.k.a. Neanderthals), a unique species of *Homo* that flourished in the Ice Ages, *H. Neanderthalensis*. *See also* 1868 ANTH.

★ Astronomy

George Bond discovers that photographs of stars reveal their magnitudes. *See also* 1834 AST; 1861 AST.

Astronomer Royal of Scotland Charles Piazzi Smyth [b. Naples, Italy, January 3, 1819, d. Ripon, England, February 21, 1900] detects infrared radiation from the full Moon using a thermocouple. *See also* 1846 AST.

❖ Biology

Louis Pasteur *Recherches sur la putréfaction* ("research on rotting") reports his discovery that fermentation is caused by microorganisms (yeast), not by chemical means as previ-

ously supposed. *See also* 1863 FOOD.

⌚ Communication

French researcher Édouard-Léon Scott de Martinville [b. 1817, d. 1879] invents the phono-autograph, an instrument that creates on a rotating drum a trace that represents sound vibrations. The instrument is used in acoustical research and is an inspiration for the soon-to-be-invented phonograph. *See also* 1877 COMM.

🌐 Earth science

William Thomas Blanford [b. London, October 7, 1832, d. London, June 23, 1905] observes that the Talchir conglomerates of India were caused by glaciation, an idea leading to the realization that ice ages had occurred many times in the past and that both hemispheres had been involved. *See also* 1840 EAR; 1874 EAR.

🍴 Food & agriculture

Inventor and food technologist Gail Borden [b. Norwich, New York, November 9, 1801, d. Borden, Texas, January 11 1874] patents his method for condensing milk using heat and a vacuum pan; only during the Civil War does his method gain widespread interest. *See also* 1885 FOOD.

◊ Materials

Sir William Henry Perkin [b. London, March 12, 1838, d. Sudbury, England, July 14, 1907] synthesizes the first artificial (aniline) dye, mauve, and starts such a fashion craze that the next few years in England are known as the Mauve Age. *See also* 1845 MATR; 1858 MATR.

Color and chemistry

Dyes are thought to predate clothing. The earliest indication of human interest in color is the preponderance of green and pink pebble tools produced by the Oldowan toolmakers. The Terra Amata *Homo erectus* site on the French Riviera, dated a million and a half years after the time of Oldowan tools, is littered with pieces of the mineral pigment ocher in its yellow, brown, red, and purple forms.

A couple of hundred thousand years later, Neandertals dyed dead relatives with red ochre before burial, suggesting that the Neandertals painted, dyed, or otherwise decorated their own bodies while alive. The root of the madder plant produces a red dye that was used for dying cloth used to wrap some Egyptian mummies. By early classical times, the Phoenicians had discovered that a Mediterranean shellfish produces a deep purple dye; in one of the early marketing successes, they arranged for the dye — royal purple — to be used only in fabrics worn by rulers. Naturally, everyone wanted it. Roman sources report that people in Great Britain used the plant woad to dye themselves blue. In the 16th century, Europeans learned that Native Americans were fond of a bright red dye from a cactus fly; both dye and fly are called cochineal.

Minerals, plants, shellfish, and insects continued in use by households and fabric manufacturers without much scientific investigation. Cornelius Drebbel, in addition to submarines and engineering works, developed in the mid-17th century a way to improve cochineal scarlet with tin and set off one of the first international fashion statements since royal purple. Thereafter, both the English and the French pursued the matter of dyestuffs and issued various handbooks and studies.

Dyes became big business in the mid-19th century with fast (nonfading) ones from coal tar. Most dyeing development was done by Germans (some while in England). This led to the great German work with organic chemistry. As colors like William Perkin's mauve and magenta, a French imitation of German fuchsin, were introduced, they swept through the fashion world — as shocking pink did in the 1930s and again in the 1950s.

Dyes work differently from pigments because dyes chemically bond with fibers. It is not surprising that dyes effective for wool, cotton, and flax also bond with parts of living creatures. German medical workers, notably Paul Ehrlich, borrowed dyes and chemistry from the fabric industry to begin the era of chemical medicine. Their artificial remedies replaced and surpassed the herbal ones just as a few decades earlier artificial coloring replaced ancient herbs.

English inventor Henry Bessemer [b. Charlton, Hertfordshire, England, January 19, 1813, d. London, March 15, 1898] introduces the Bessemer process for producing inexpensive steel. The process is based on his 1855 patents on the basic process for blasting air into molten iron and coke to make the fire hotter and to remove carbon and also on the 1856 patents of Robert Mushet [b. Coleford, England, 1811, d. January 1891] for removing sulfur impurities from steel. Mushet had failed to stamp his patent application properly and would have died in poverty if Bessemer had not paid him a pension of 300 pounds sterling per year during the last years of his life. *See also* 1852 MATR; 1876 MATR.

Friedrich Siemens [b. Menzendorf, Hanover, Germany, December 8, 1826, d. Dresden, Germany, May 24, 1904] develops the regenerative furnace. It

burns previously unburnt gases for greater efficiency and is the forerunner of the open-hearth steel process. *See also* 1852 MATR; 1868 MATR.

♥ Medicine & health

Karl Ludwig is the first to keep animal organs alive outside the body, which he does by pumping blood through them. *See also* 1905 MED.

* Physics

William Thomson (Lord Kelvin) introduces the term *kinetic* to describe the energy of motion. *See also* 1853 PHY.

I Tools

Robert Bunsen and Henry Roscoe invent the actinometer, which measures the heating power of electromagnetic radiation. The main use is to measure solar energy for meteorological applications. *See also* 1881 TOOL.

→ Transportation

The plans for the construction of the Suez Canal from the Mediterranean to the Red Sea by Alois Negrelli von Moldelbe [b. Primiero (Italy), January 23, 1799, d. Vienna, October 1, 1858] are accepted. The canal will be built starting in 1859, after Negrelli's death. *See also* 640 CE TRAN; 1859 TRAN.

1857

▲ Archaeology

Auguste Mariette is appointed director of all Egyptian excavations and antiquities. *See also* 1851 ARCH.

★ Astronomy

James Clerk Maxwell proves mathematically that Saturn's rings are composed of many small bodies orbiting the planet. *See also* 1848 AST; 1895 AST.

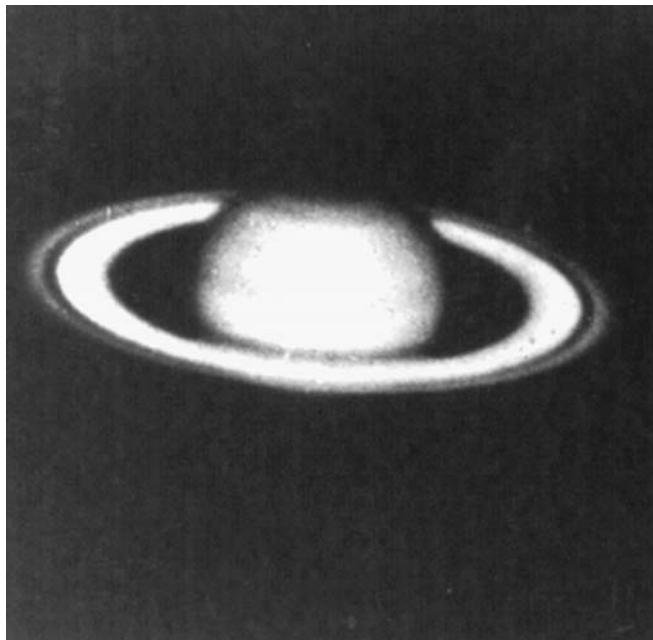
George Bond is the first to photograph a double star, Misar, and obtain images of both components. *See also* 1802 AST; 1892 AST.

Tables de la lune ("lunar tables") of Peter Andreas Hansen [b. Tondern, Denmark, December 8, 1795, d. Gotha, Germany, March 28, 1874] are printed by the British government and used thereafter in nautical almanacs. *See also* 1824 AST; 1878 AST.

Léon Foucault starts production of silver-coated glass telescope mirrors, which will replace metal mirrors used in previous reflecting telescopes.

↗ Biology

Gregor Mendel starts the experiments with peas in his garden that will lead to his working out the laws of heredity. *See also* 1860 BIO.



SATURN AND RINGS AS SEEN IN THE 19TH CENTURY Today we are used to the clear images of Saturn from space probes like *Voyager 2* and from the *Hubble Space Telescope*, but the only ringed planet known in the 19th century was a rather fuzzy-looking object. The division recognized by Cassini was visible, demonstrating that the rings cannot be a single object, but it was difficult to tell the nature of the rings. Maxwell proved what others had begun to suspect — the rings are composed of many small bodies occupying a band of orbits.

Zoologist Spencer Fullerton Baird [b. Reading, Pennsylvania, February 3, 1823, d. Woods Hole, Massachusetts, August 19, 1887] produces a checklist of North American birds that will become the

basis of population studies of birds in the United States.

Albrecht von Kölliker finds structures in muscle cells that he calls *sarcosomes*. By 1898 they are shown to be present in a wide variety of cells and are given the name *mitochondria*.

Chemistry

Friedrich Kekulé is the first to determine that carbon has a valence of four, meaning that a carbon atom can, for example, link to four valence-1 hydrogen atoms (methane) or two valence-2 oxygen atoms (carbon dioxide). See also 1858 CHEM.



Friedrich August von Stradonitz Kekulé

[b. Darmstadt, Hesse, Germany, September 7, 1829, d. Bonn, Germany, July 13, 1896]

The field of organic chemistry was first put on a sound basis by Kekulé with his determination that carbon has a valence of 4. Kekulé also found that of the four bonds for each carbon atom, one of the bonds can link to another carbon atom, permitting carbon-based molecules to form as chains.

Kekulé's recognition of such structures provided an explanation for isomers and other phenomena. His half-dreamed vision in 1861 of the benzene ring (in his dream a snake is eating its tail) became the basis for the chemistry of aromatic compounds.

Communication

An attempt at laying a transatlantic telegraphic cable fails when the cable breaks at a depth of 1800 m (6000 ft) and cannot be recovered. See also 1851 COMM; 1858 COMM.

Energy

Alexandre-Edmund Becquerel experiments with coating electric discharge tubes with luminescent materials, a process that eventually leads to fluorescent lamps.

Werner von Siemens designs the shuttle winding for the armature of the electric generator (dynamo), a major step toward the development of a method of obtaining electrical energy from a generator without using permanent magnets. The design and other research will be published by Werner's brother William in 1867. See also 1838 ENER.

Food & agriculture

French engineer Ferdinand Carré [b. 1824, d. 1900] builds a refrigeration machine based on the expansion of ammonia gas. The device can produce temperatures as low as -30°C (-22°F). See also 1873 FOOD.

Gregor Johann Mendel

[b. Heinzendorf, Silesia (Poland), July 22, 1822, d. Brünn, Bohemia (Brno, Czech Republic), January 6, 1884]

A monk who experimented with garden peas and other plants in his spare time, Mendel discovered the fundamental principles of genetics. Between 1856 and 1863 he grew at least 28,000 pea plants and analyzed characteristics such as height, flower color, and pod shape. He carefully cross-pollinated plants, then noted what sort of plants developed from the seeds. In an 1865 paper he characterized what came to be called Mendel's laws. The law of unit characters says that characteristics of an individual are controlled by hereditary factors (now called genes) and that these factors occur in pairs. The law of dominance says that some inherited factors are dominant and can mask other, recessive factors. The law of segregation says that the factors of a pair are separated during reproduction, so only one goes to a particular offspring. Mendel's principle of incomplete dominance is that for some characteristics neither gene is dominant. The importance of Mendel's work was not recognized until 1900, when three botanists working independently reached similar conclusions and, in the process, discovered his paper.



❖ Materials

E.J. Hughes obtains a patent for an artificial “silk” made from starch, gelatin, resin, tannins, fats, and other ingredients. *See also* 1855 MATR; 1884 MATR.

American Joseph Cayetty invents the modern form of toilet tissue. Its use spreads outside the United States only after the First World War. *See also* 589 MATR.

American metallurgist William Kelly, learning of similar work by Henry Bessemer, patents the “air-boiling process” for making steel in the United States. *See also* 1852 MATR.

♥ Medicine & health

About this time a special mixture of resins and soapstone known as impression compound begins to replace plaster of Paris for making impressions of teeth.

Claude Bernard discovers glycogen, used by the body to store glucose in the liver. When glucose is needed for energy, the liver converts the glycogen back to glucose — the first demonstration of catabolism. *See also* 1848 BIO; 1891 BIO.

* Physics

Gustav Kirchhoff discovers that static electricity forces and magnetic forces are related to each other by a constant that turns out to be the speed of light in a vacuum, a clue that electromagnetism has something to do with light. *See also* 1873 PHY.

Ueber die art der bewegung welche wir Wärme nennen (“on the kind of motion that we call heat”) by Rudolf Clausius establishes his kinetic theory of heat on a mathematical basis. It also explains how



Gustav Robert Kirchhoff

[b. Königsberg (Kaliningrad, Russia), March 12, 1824, d. Berlin, October 17, 1887]

In 1845 Kirchhoff developed the laws governing current and resistance in electrical networks. In 1859 Kirchhoff and Robert Bunsen invented the spectroscope, obtaining spectrums from glowing samples. Kirchhoff recognized that elements can be identified this way and that dark lines in a star's spectrum represent elements in gas surrounding the star. He calculated the type of radiation to be emitted by a heated black body. Resolving contradictions between Kirchhoff's black-body theory and experiment led to the development of quantum theory.

evaporation occurs. *See also* 1850 PHY; 1860 PHY.

I Tools

Jules Lissajous [b. Versailles, France, March 4, 1822, d. Plombières-les-Dijon, France, June 24, 1880] invents a machine for making Lissajous figures, curves obtained by superimposing different simple harmonic curves at right angles to each other.

Allen Benjamin Wilson improves the sewing machine developed by Isaac Singer. *See also* 1851 TOOL.

↗ Transportation

Elisha Otis installs the first safety-equipped passenger elevator in a five-story downtown New York City china and glassware store. *See also* 1854 TRAN; 1860 TRAN.

The excavation of the tunnels for the London Underground railroad (subway) starts, using a method of iron casings developed by Marc Isambard Brunel while building the first tunnel under the Thames. *See also* 1863 TRAN.

1858

★ Astronomy

Englishman William Usherwood takes the first photograph of a comet (Donati's).

Warren De la Rue develops the photoheliograph, which makes taking photographs of the Sun routine. *See also* 1891 AST.

↗ Biology

The secretary of the Linnaean Society reads communications from Darwin and Alfred Wallace, an unpublished manuscript of Darwin's from 1844, a letter from Darwin to Asa Gray written in 1857, and a letter from Wallace to Darwin from February 1858. All three describe the theory of evolution by natural selection. *See also* 1844 BIO; 1859 BIO.

◊ Chemistry

Stanislao Cannizzaro [b. Palermo, Sicily (Italy), July 13, 1826, d. Rome, May 10, 1910] learns of the hypothesis of Amedeo Avogadro that all gases at a given temperature contain the same number of particles, the essential idea that leads Cannizzaro to clarify the concept of a molecule. *See also* 1811 CHEM; 1860 CHEM.

Friedrich Kekulé shows that carbon's valence of 4 can account for the different isomers of organic compounds. He reports that this idea came to him in a half-asleep dream on a London bus, featuring

atoms dancing together and forming chains, essentially the concept of the chemical bond. Archibald Scott Couper [b. Kirkintilloch, Scotland, March 3, 1831, d. Kirkintilloch, March 11, 1892] independently introduces the concept of bonds into chemistry at this time. Couper also assumes that carbon atoms form the backbone of organic compounds. *See also* 1857 CHEM; 1865 CHEM.

⌚ Communication

The first successful transatlantic telegraphic cable is laid, although it breaks after three months (an attempt the previous year failed before it was entirely laid). *See also* 1857 COMM; 1866 COMM.

Louis Ducos du Hauron [b. Langon, France, December 8, 1837, d. Agen, France, August 31, 1920] patents a method of color printing based on photographs made on zinc plates through color filters. *See also* 1855 COMM; 1861 COMM.

Julius Plücker observes light emitted by electrons hitting the glass walls of a partially evacuated vacuum tube. This is a precursor of the cathode-ray tube still used in many applications, such as television and computer monitors. *See also* 1878 COMM.

The theory of evolution

Charles Darwin may be safely called the greatest biologist of the 19th century, but his ideas about evolution were neither entirely new nor complete. Indeed, it is one of the famous stories of science that Darwin's theory of evolution was made public in 1858 only because Alfred Wallace had reached the same conclusions as Darwin and mailed these to Darwin himself. Ever generous, Darwin arranged to present his work and Wallace's in the same session, so that neither would have priority, although Darwin had formulated the basic ideas many years earlier. It is unlikely, however, that evolution would have had the immediate impact that it did if the theory had been put forth by Wallace alone. Darwin was already well known for his account of the voyage of the *Beagle* and for his scientific work on that voyage. Furthermore, Darwin's *On the Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life* — better known simply as *The Origin of Species* — published November 24, 1859, is one long, persuasive argument for the theory, which convinced many biologists of its truth through many examples.

But before there was *The Origin of Species* or Wallace's conclusions, biology had to progress to a point where the existence of evolution seemed reasonable and therefore deserving of a scientific explanation.

For one thing, there was no point to explaining the origin of species until a species was defined. The modern concept of species began with John Ray's 1686 definition, based on common descent (a point of view revived more recently as cladism). The definition was put into the form we still teach today by comte de Buffon in 1749: A species is a group of interbreeding individuals who cannot breed successfully outside the group.

In Darwin's time, scientists considered species to be immutable. Even though dogs or cabbages could be bred to many different shapes, for example, no one could develop a breed of dog that is of the cat species or breed a cabbage into an onion. Ancient writers who had a less clear concept of species believed that wheat seed could sometimes sprout as millet.

Most scientists of the 17th and 18th centuries also believed in a doctrine called *preformation*. This concept existed in two much argued versions: In one, the adult existed in a tiny version, or was preformed, in the egg; in the other, the adult was preformed in the sperm. Preformation would seem to preclude one species giving birth to a member of another species. As the science of embryology became more precise, however, the doctrine of preformation — a potential barrier to a theory of evolution — was replaced by the recognition of epigenesis, the development of the embryo from undifferentiated tissues.

Another factor in creating the climate for evolution was the emerging understanding of fossils as the remains of living creatures and the realization that many fossils were of species that no longer existed.

Late in the 18th century, yet another precondition was met — an understanding that the time required for evolution to occur was present in Earth's history. Both Abraham Gottlob Werner and James Hutton proposed processes for the development of geological features that required great stretches of time for Earth to have existed. Large amounts of time meant that evolution could take place so slowly that it would not be observed among living creatures. This was a necessary precondition, since evolution at the species level is not observable during a lifetime.

With that background, many scientists and near scientists of the first half of the 19th century believed in some form of evolution. Lamarck, one of the first evolutionists, thought, correctly, that the environment causes species to evolve. But he also thought that acquired characteristics of the parent could be inherited by the offspring; this was greeted with much disbelief in Lamarck's day and is not accepted today. Charles Darwin's own grandfather, Erasmus Darwin (one of the near scientists), offered a general theory of evolution by generation; it included not only living organisms but also Earth itself.

In England the most influential evolutionist before Darwin was Robert Chambers. His 1844 *Vestiges of Creation* influenced both Darwin and Wallace. Indeed, Wallace recognized that Chambers had the fact of evolution but did not have an explanation for it, setting Wallace on his own search for an explanation. Chambers was not a careful scientist, however, and his errors put off many professional scientists.

After publication of *Origin of Species* many — although not all — scientists were converted both to evolution and to the Darwin-Wallace theory of natural selection. The public was less convinced at first, especially those who took Darwinism to be atheistic (which Darwin did not consider it or himself to be). Many people also rejected Darwin's explicitly stated idea that humans and great apes share an ancestor. Two notable opponents of natural selection were Samuel Butler, the author of *The Way of All Flesh*, and George Bernard Shaw. Butler wanted to return to the ideas of Erasmus Darwin, and Shaw believed in a mystical life force. In the end, however, the theory of evolution and natural selection won all except those who continued to think that it contradicts the Biblical account of Creation.

The theory of evolution did not arise fully formed in 1859, however. Modern evolutionists continue to improve on Darwin and Wallace, and a few have even rejected their ideas. New ideas have emerged, such as the concept of mutation and the laws of heredity. These new ideas combined with natural selection to form the basis for neo-Darwinism, the prevalent theory of evolution during most of the 20th century. Since the 1940s, a theory of evolution has arisen that calls for rapid bursts of evolutionary change between long periods of species stability. This theory, "punctuated evolution," has most recently been articulated by Stephen Jay Gould and Niles Eldredge. The discovery of how heredity works via DNA has more exactly explained the mechanisms of the theory of evolution as well.

Cromwell Fleetwood Varley [b. London, April 6, 1828, d. Bexleyheath, England, September 2, 1883] improves the pneumatic system for sending telegrams between the Stock Exchange and the International Telegraph Company in London. Compressed air and a partial vacuum (suction) are both used as motive powers, allowing documents to travel in both directions. *See also* 1853 COMM; 1859 COMM.

Earth science

Lawyer William Parker Foulke, while vacationing in Haddonfield, New Jersey, finds nearly half of the skeleton of a dinosaur, the most complete fossil of its kind found to that time. The scientific name of *Hadrosaurus foulkii* ("Foulke's bulky lizard") will be assigned to the dinosaur. *See also* 1842 EAR.

Energy

The Foreland lighthouse in Kent, England, is the first to be equipped with electrically powered arc lights. *See also* 1809 ENER.

Food & agriculture

Ezra J. Warner [b. Middlebury, Vermont, March 8, 1841, d. 1910] of Waterbury, Connecticut, invents the can opener, nearly 20 years after U.S. canners switched from jars to metal cans and almost 50 years after the metal can was invented (in 1810). Previously, metal cans were expected to be opened with general-purpose tools, such as a hammer and a chisel. *See also* 1839 FOOD.

Materials

Henry Deacon [b. London, July 30, 1822, d. Widnes, England, July 23, 1876] introduces

a process for making chlorine from hydrochloric acid and oxygen using a temperature of 400°C (750°F) and a copper chloride catalyst absorbed on pumice stone. *See also* 1851 MATR; 1861 MATR.

August Wilhelm von Hofmann makes the artificial dye magenta (often called fuchsin, from its resemblance to the color of the flower of the fuchsia) from coal tar. It is quickly copied by French dyers, who name it the following year after the French defeat the Italians at the battle of Magenta. By 1860 it is being made in Germany as well. *See also* 1856 MATR.

Mathematics

Notes on Matters Affecting the Health, Efficiency and Hospital Administration of the British Army by Florence Nightingale [b. Florence (Italy), May 12, 1820, d. London, August 13, 1910] contains numerous innovative statistical diagrams, including polar-area charts, which Nightingale invents. In a polar-area chart, each statistic is represented by the area of a wedge in a circular diagram.

Scottish lawyer Alexander Henry Rhind [b. 1833, d. 1863] purchases the Egyptian papyrus subsequently known as the Rhind papyrus. It proves to be one of the two main keys to understanding Egyptian mathematics. *See also* 1650 BCE MATH.

Augustus de Morgan formulates de Morgan's laws, two important laws in set theory. As originally stated they refer to sets as aggregates, saying that the contrary of an aggregate is the compound of the contraries of the aggregates

and also the contrary of a compound is the aggregate of the contraries of the components. In terms of set theory, this states that the complement of the union of two sets is the intersection of the complements of the sets, while the complement of the intersection of two sets is the union of their complements. *See also* 1847 MATH; 1889 MATH.

Arthur Cayley develops the algebra of matrices in the context of the theory of invariant transformations. *See also* 1850 MATH; 1872 MATH.

Medicine & health

Rudolph Virchow in *Die Cellularpathologie* ("cellular pathology") describes methods and objectives of pathology and demonstrates that cell theory applies to diseased as well as healthy tissue. He proclaims the theory that disease is caused when cells refuse to cooperate with other cells, which is true of some diseases, such as cancer and lupus, but not true of infectious diseases. *See also* 1855 BIO; 1876 MED.

German psychologist Wilhelm Wundt [b. Neckerau, Germany, August 16, 1832, d. Leipzig, Germany, August 31, 1920] begins publication of *Beiträge der Sinneswahrnehmungen* ("contribution to the theory of sensory perception"), which will be completed in 1862. It becomes one of the founding works of experimental psychology. *See also* 1873 MED.

Franciscus Cornelis Donders [b. Tilburg, Netherlands, May 27, 1818, d. Utrecht, Netherlands, March 24, 1889] discovers that farsightedness can be caused by too-shallow eyeballs. *See also* 1801 MED.

The first practical powered dental drill, driven by a foot pedal, is constructed. *See also* 1790 MED; 1872 MED.

Physics

Julius Plücker shows that cathode rays bend under the influence of a magnet, suggesting that they are connected with charge in some way; this is an early step along the path that will lead in 1897 to the discovery that cathode rays are composed of electrons. *See also* 1845 PHY.

Tools

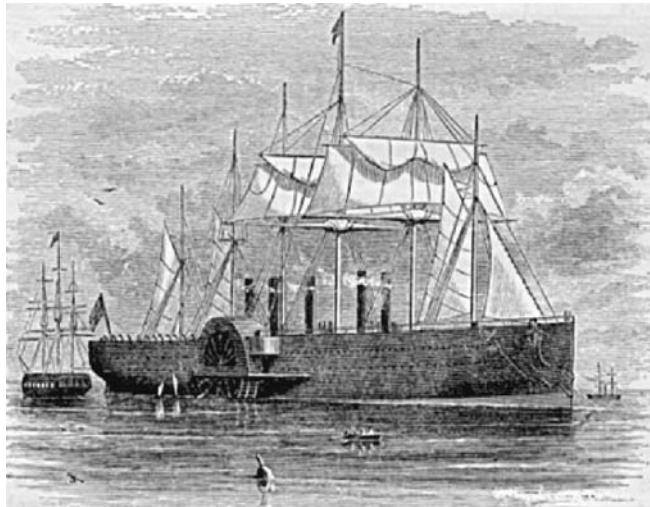
Théophile Guibal [b. Toulouse, France, 1813, d. Paris, 1888] invents the propeller fan, first used to refresh air in mines.

Germain Sommeiller [b. Bonneville, France, February 15, 1815, d. Bonneville, July 11, 1871] invents the pneumatic drill, which is used for the excavation of the Mont Cenis Tunnel. *See also* 1832 TOOL; 1870 TRAN.

Transportation

Isambard Brunel launches the *Great Eastern* on January 31. Driven with both paddle wheels and a propeller, with a displacement of 22,500 tons, it remains the largest ship in service during the 19th century — 210 m (693 ft) long and capable of carrying 4000 passengers. In 1866 it serves in laying the first transatlantic cable, but then is retired from active service, although exhibited to the public. It is scrapped in 1888. *See also* 1843 TRAN.

The first aerial photograph is taken from the balloon *Nadir* as it flies over Paris. *See also* 1794 TRAN.



THE GREAT EASTERN AT SEA With a double hull of iron held together by 3,000,000 rivets to protect it from sinking, the *Great Eastern* confounded its detractors who claimed that a ship that size would break in two from its own weight. The rivets were installed by an army of small children working between the hulls to hold the hot rivets in place so adults outside the hulls could bash the rivet heads flat. The ship not only had the paddle wheel and six masts with sails visible, but also a propeller under the water line. It was so large that most docks of the time could not accommodate it.

1859

★ Astronomy

On October 27 Gustav Kirchhoff and Robert Bunsen announce the first measurements of frequencies of spectral lines, a powerful new way to identify elements from the light they emit or absorb. Kirchhoff relates dark lines in the solar spectrum to bright spectra of elements, concluding that gases absorb light of the same frequency as they emit and opening the way to detecting elements in light from stars and glowing gases in space. Kirchhoff recognizes that sodium is found on the Sun. See also 1854 AST; 1860 CHEM.

Richard Christopher Carrington [b. London, May 26, 1826, d. Churt, Surrey, England, November 27, 1875] on September 1 becomes the first astronomer to recognize a

solar flare. He discovers that the Sun does not rotate as a single unit; instead the equator rotates in 27.5 days, while regions near the pole rotate in 25 days. *See also* 1859 EAR.

German astronomer Friedrich Wilhelm August Argelander [b. Memel (Klaipeda, Soviet Union), March 22, 1799, d. Bonn, Germany, February 17, 1875] begins publication of the *Bonner Durchmusterung* (Bonn survey); when complete in four volumes in 1862 it will list the positions of 457,848 stars. *See also* 1864 AST.

◆ Biology

Darwin's *On the Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life*, usually known as *The Origin of Species*, explains in detail his principle of natural selection and its influence on the evolu-

ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

OR THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE
FOR LIFE.

BY CHARLES DARWIN, M.A.,

FELLOW OF THE ROYAL, GEOLOGICAL, LINNÆAN, ETC., SOCIETIES;
AUTHOR OF 'JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE'S VOYAGE
ROUND THE WORLD.'

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

The right of Translation is reserved.

TITLE PAGE OF THE ORIGIN OF SPECIES The full title of Charles Darwin's most famous book reveals that it is not just about evolution but provides a mechanism that accounts for how species are created. The subtitle, with the phrases "favoured races" and "struggle for life," however, suggests the later misuse of Darwin's theory in support of social ideas by Herbert Spencer and others.

tion of different species. *See also* 1858 BIO; 1860 BIO.

▷ Chemistry

Adolph Wilhelm Hermann Kolbe develops the reaction named after him, which leads to the large-scale synthesis of

acetylsalicylic acid — aspirin. *See also* 1893 MED.

Alexander Mikhailovich Butlerov [b. Tschistopol, Russia, September 6, 1828, d. Biarritz, France, August 17, 1886] accidentally discovers formaldehyde. Butlerov is among the

first to investigate the structure of organic compounds.

Communication

John Dancer demonstrates microdot photography; he succeeds in photographing pages of books onto dots 1/1600 part of a square inch. *See also* 1840 COMM.

Paul Broca starts the Société d'Anthropologie.

Richard Spelman Culley and Robert Sabine introduce a radial pneumatic mail system in London for the British Post Office; it carries telegrams from a central telegraph office to branches. *See also* 1858 COMM; 1868 COMM.

Earth science

Balfour Steward is the first to connect the solar flare to a disruption about 18 hours later in Earth's magnetic field. *See also* 1859 AST.

Ecology & the environment

John Tyndall shows that water vapor is transparent to light rays but not to heat, noting that "every variation of this [atmospheric] constituent must produce a change in climate." *See also* 1905 ECOL.

Energy

Engineer Edwin Laurentine Drake [b. Greenville, New York, March 29, 1819, d. Bethlehem Pennsylvania, November 8, 1880], often referred to by his nickname of Colonel Drake, drills the world's first oil well in Titusville, Pennsylvania. He strikes oil on August 28, starting a process that will eventually fund much large-scale geological research in the search for more oil. This first deliberate oil well, drilled by



THE FIRST WELL DRILLED TO EXTRACT OIL People had long known of petroleum from seeps in the ground, but there seemed to be little commercial use until 1853 when Samuel Kier began to make kerosene from it, a cheap substitute for the whale oil commonly used in lamps. In 1855 Benjamin Siliman at Yale, hired by George H. Bissell, discovered ways to make gasoline and paraffin also from petroleum. Bissell then arranged for Colonel Drake to drill the first oil well. That well and those that quickly followed led to fortunes for Bissell and other investors in the venture.

Pennsylvania Rock Oil Company, is 23 m (75 ft) deep and delivers 1600 L (422 gal) of oil per day. *See also* 1860 ENER.

William Rankine writes *Manual of the Steam Engine and*

other Prime Movers, introducing engineers to thermodynamics and the Rankine cycle; he also coins most of the modern terms used in the field. *See also* 1824 ENER.

Gaston Planté [b. Orthez, France, April 22, 1834, d. Paris, May 21, 1889] invents the lead acid storage battery, which produces electricity from a chemical reaction and which can be recharged again and again. *See also* 1839 ENER.

Materials

Marcel Morren observes that an electric spark created with carbon electrodes in a hydrogen atmosphere produces an unknown gas, which we now know as acetylene (Morren called it "carbonized hydrogen"). *See also* 1836 CHEM; 1862 MATR.

Medicine & health

German chemist Albert Niemann isolates cocaine from the leaves of *Erythroxylon coca*. The stimulant properties of cocaine had long been known to natives of South America; Europeans had learned of them after their conquest of the Inca empire. *See also* 1884 MED.

Physics

Gustav Kirchhoff finds that one consequence of the second law of thermodynamics is that, at a uniform temperature, it is impossible to distinguish between objects by the light they radiate, even if they are glowing hot; an outside light source must be provided. *See also* 1847 PHY.

Transportation

Viscomte Ferdinand Marie de Lesseps [b. Versailles, France, November 19, 1805, d. La Chenaie, France, December 7, 1894] turns over the first shovelful of earth to start construction of the Suez Canal from the Red Sea to the Mediterranean. Built according to

the plans of Alois Negrelli von Moldelbe, the canal is completed ten years, later on August 15, 1869. *See also* 1856 TRAN; 1869 TRAN.

1860

★ Astronomy

Warren De la Rue photographs a solar eclipse and confirms that the prominences visible come from the Sun and not from the Moon. *See also* 1842 AST.

Canadian-American astronomer Simon Newcomb [b. Wallace, Nova Scotia, March 12, 1835, d. Washington, DC, July 11, 1909] demonstrates that it is unlikely that the asteroids orbiting between Mars and Jupiter are the survivors of a planet that once occupied an orbit in that region, but which somehow broke into pieces. *See also* 1801 AST.

Biology

About this time Gregor Mendel discovers the laws of heredity, which he communicates to Karl Wilhelm von Nägeli, who is not interested and does not pursue the matter. *See also* 1857 BIO; 1900 BIO.

Louis Agassiz attacks Darwin's *Origin of Species*, rejecting the idea of evolution of the species and arguing that each species has been created separately. *See also* 1859 BIO.

Thomas Henry Huxley [b. Ealing, Middlesex, England, May 4, 1825, d. Eastbourne, Sussex, England, June 29, 1895] clashes with Bishop Samuel "Soapy Sam" Wilberforce [b. 1805, d. 1873] about evolution at the annual meeting of the British Association for the Advancement of Science. When Bishop Wilber-

force asks Huxley which branch of the monkey family he is descended from, Huxley replies that he would rather have a miserable ape for a grandfather than a man who would employ his faculties and influence to ridicule scientific ideas. By all accounts, this wins that day's debate for Huxley. *See also* 1619 BIO.

Chemistry

Gustav Kirchhoff and Robert Bunsen introduce the spectroscope for chemical analysis of metals placed in a flame. Kirchhoff and Bunsen announce on May 10 the discovery of cesium (Cs), the first element found as a result of spectroscopy. The name *cesium* means "sky blue," referring to the color of its spectrum. *See also* 1859 AST.

Friedrich Kekulé organizes the First International Chemical Congress in Karlsruhe, Germany, the first international meeting of scientists ever held. At the meeting Stanislao Cannizzaro revives Amedeo Avogadro's hypothesis that equal volumes of all gases at a given temperature and pressure contain the same number of molecules, making the hypothesis popular for the first time. He also emphasizes the importance of atomic weights. *See also* 1858 CHEM; 1866 CHEM.

Communication

About this time Sir William James Herschel, working in India, begins to use fingerprints as a way of identifying government prisoners, but this concept is not known outside of India. *See also* 1823 COMM; 1880 COMM.

Earth science

Paleontologist Hermann von Meyer is given a rare fossil of soft tissue. It is the fossilized imprint of a feather, the first sign of what Meyer names *Archaeopteryx*. *Archaeopteryx* will be recognized for many years as the earliest bird. *See also* 1861 EAR.

Energy

A patent for a method of obtaining high-boiling fractions of petroleum, called "cracking," is issued to Downer's Kerosene Oil Company in Boston. *See also* 1859 ENER.

Jean-Joseph-Etienne Lenoir [b. Mussy-la-Ville, Belgium, January 12, 1822, d. Varenne-St. Hilaire, France, August 4, 1900] develops a two-stroke internal combustion engine with a single cylinder and with electric ignition. It uses coal gas as a fuel. It is, however, very inefficient. *See also* 1824 ENER; 1862 ENER.

John T. Way demonstrates

that light can be produced by sending electricity through mercury vapor, an application of the Geissler tube. The Geissler tube is an early form of Crookes tube. *See also* 1855 PHY; 1892 ENER.

Joseph Swan experiments with electric light generated by carbon filaments. *See also* 1856 ENER; 1879 ENER.

Food & agriculture

The combine harvester for grain (it combines a picker and a thresher) is developed.

In France Leonce-Eugene Grassin-Baledans patents the use of twisted strands of sheet metal as fencing and to protect trees; this patent is considered the precursor to barbed wire. *See also* 1868 FOOD.

Medicine & health

Vulcanized rubber begins to be used as a baseplate material for dentures, replacing porcelain. *See also* 1790 MED.

Physics

James Clerk Maxwell and, separately, Ludwig Boltzmann develop the study of the statistical behavior of molecules in a gas, known today as the Maxwell-Boltzmann statistics. *See also* 1924 PHY.

Ludwig Edward Boltzmann

[b. Vienna, Austria, February 20, 1844, 1906, d. Duino, near Trieste (Italy), September 5, 1906]

Boltzmann established the mathematical basis of thermodynamics, especially the definitions of heat and entropy in terms of the movement and energy of particles in gases. He completed a statistical analysis of how molecules behave in gases (the Maxwell-Boltzmann statistics), which describes one of three ways assemblies of particles can distribute themselves (the others are the Fermi-Dirac statistics for particles that behave like electrons and the Bose-Einstein statistics for particles that behave like photons).



Michael Faraday describes his experiment of lowering the freezing point of water by applying pressure in “Pressure Melting Effect,” presented to a meeting of the Royal Society.

→ Transportation

Elisha Otis patents a steam-driven elevator. *See also* 1857 TRAN.

1861

★ Astronomy

Johann Karl Friedrich Zöllner [b. Berlin, November 8, 1834, d. Leipzig, Germany, April 25, 1882] invents the astronomical photometer for measuring stellar magnitudes. *See also* 1856 AST.

↗ Biology

Anatomist Max (Johann Sigismund) Schultz [b. Freiburg, Germany, March 25, 1825, d. Bonn, Germany, January 16, 1874] studies the main contents of cells, now known as cytoplasm, and shows that this material is approximately the same for all forms of life. *See also* 1851 BIO.

Rudolf von Kölliker is among the first to interpret the development of the embryo in terms of cell theory. *See also* 1845 BIO.

;element Chemistry

Gustav Kirchhoff and Robert Bunsen discover a bright red line in a spectrum that represents a new element, which they name rubidium (Rb) for “red.” William Crookes also uses a spectroscope to discover thallium (Tl) as a bright green line in the spectrum of a selenium ore he is investigating; *thallium* means “green twig.” *See also* 1860 CHEM.

Austrian chemist Johann Joseph Loschmidt [b. Putschirn, Bohemia (Pocerny, Czech Republic), March 15, 1821, d. Vienna, July 8, 1895] extends Archibald Scott Couper’s idea of using single lines for single bonds in organic chemistry to using double lines for double bonds, and so forth. *See also* 1858 CHEM.

↳ Communication

James Clerk Maxwell, assisted by photographer Thomas Sutton, demonstrates in London the first color reproduction using a photographic process, projecting three separate images of the Scottish flag taken through red, green, and violet filters and matching them to form a single picture, using light of the same three colors to produce the color image. *See also* 1873 COMM.

Schoolteacher Johann Philipp Reis [b. Gelnhausen, Germany, January 7, 1834, d. Friedrichsdorf, Germany, January 14, 1874] transmits musical tones over 100 m (300 ft) with a device he terms a telephone. The microphone consists of a metal point in contact with a metal strip attached to a membrane; the receiver consists of a metal needle placed inside a solenoid and attached to a resonator. The length of the

metal needle changes because of magnetostriction (variations in length caused by a magnetic field). Loud sounds tend to cut the connection between the needle and the resonator, however. Although Reis later claims credit for the invention of telephone, Bell’s successful device works on a slightly different principle and it is not known whether Reis ever tried to transmit speech. *See also* 1846 PHY; 1876 COMM.

⊕ Earth science

A complete fossil of *Archaeopteryx* with clear impressions of wings as well as feathers is found in the same formation at the Solnhofen quarry in Germany where the first feather had been discovered. In September the new fossil is announced by Hermann von Meyer, who has been given it to describe. Later five more specimens will be found, the next in 1877. *See also* 1860 EAR.

◊ Materials

Irish telegrapher Joseph May observes that sunlight affects the electrical resistance of instruments made from selenium; inventors soon use this discovery to produce crude and impractical television devices. *See also* 1873 COMM.

Ernest Solvay [b. Rebecq, Bel-

gium, April 16, 1838, d. Brussels, May 26, 1922] discovers a process for making sodium bicarbonate from salt water, ammonia, and carbon dioxide. The Solvay process is much more economical than preceding techniques for manufacturing sodium bicarbonate. Regular production using the method begins in 1863. *See also* 1858 MATR.

Σ Mathematics

Bernhard Riemann’s *Über eine Frage der Wärmeleitung* (“on a question in the conduction of heat”) develops the mathematics of quadratic differential forms, a part of tensor theory, which will later become important in general relativity. *See also* 1915 PHY.

♥ Medicine & health

Paul Broca is the first to demonstrate that a particular region in the brain (Broca’s area) is connected to a particular faculty, in this case the faculty of speech, by discovering a lesion in the brain during an autopsy on a man who could not speak intelligibly. *See also* 1843 MED; 1870 BIO.

Physiologist Karl von Voit [b. Amberg, Germany, October 31, 1831, d. Munich, January 31, 1908] demonstrates that different foods do not provide energy for different body functions.

Paul Broca (a.k.a. Pierre-Paul Broca)

[b. Sainte-Foy-la-Grande, France, June 28, 1824, d. Paris, July 9, 1880]

A noted medical researcher who made important contributions on tumors and aneurysms (pathological dilations of blood vessels), Broca is best remembered for his discovery of the part of the human brain that controls speech, now called Broca’s area. As a result of his studies of skeletons exhumed from an ancient cemetery in Paris, Broca also developed a strong interest in physical anthropology. He established the Society of Anthropology of Paris and was a founder of the French Association for the Advancement of Science.



For example, proteins break down at the same speed whether or not work is being done. *See also* 1865 FOOD.

I Tools

Joseph Rogers Brown [b. Warren, Rhode Island, January 26, 1810, d. Isles of Shoals, New Hampshire, July 23, 1876] of Brown and Sharpe invents the universal milling machine to make the grooves in twist drills used for making musket parts. The milling machine can also do all kinds of spiral cutting as well as gear cutting. *See also* 1818 TOOL; 1862 TOOL.

Transportation

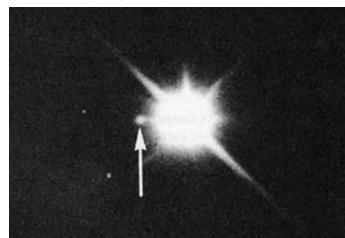
Pierre Michaux in France introduces a bicycle propelled by pedals attached to the front wheel and used as cranks. This version of the bicycle was often called the boneshaker in English since it had no springs and, at first, used steel tires. *See also* 1839 TRAN; 1869 TRAN.

On October 1 ship designer John Ericsson lays the keel on the *Monitor*, which will become the first ironclad ship on the Union side of the Civil War to see actual battle. Several ships on the Mississippi River are also armored by the Union at this time with 6 cm (2.5 in.) of iron plate, but Ericsson's *Monitor* is the first designed from the ground up to be ironclad. *See also* 1862 TRAN.

1862

▲ Archaeology

American Egyptologist Edwin Smith [b. Connecticut, 1822, d. 1906] purchases a papyrus that, when translated in 1930, turns out to be a summary of the surgical practices of



SIRIUS A AND ITS COMPANION, SIRIUS B Sirius A ranks as the brightest star as seen from Earth not only because it is intrinsically bright but also because it is near — only 8.6 light-years away. Its proximity helped astronomers to discover that Sirius A is orbited by a companion star whose gravitational force pulls the bright star back and forth. Originally known as the "dark" companion because the faint Sirius B was not observed in the glare from Sirius A, better telescopes revealed the companion.

ancient Egypt, based on a text that was probably originally written around 2500 BCE (although the Edwin Smith Surgical Papyrus itself dates from about 1550 BCE). *See also* 1550 BCE MED; 1873 ARCH.

★ Astronomy

On January 31, while testing a new telescope lens, Alvan Clark [b. Ashfield, Massachusetts, 1804, d. 1887] and his son Alvan Graham Clark [b. Fall River, Massachusetts, July 10, 1832, d. 1897] observe Sirius B, the "dark" companion (now known to be a white dwarf) of the bright star Sirius. *See also* 1841 AST; 1896 AST.

The first great refracting telescopes are constructed, including the Newall 64-cm (25-in.) telescope made by York instrument maker Thomas Cooke [b. 1807, d. 1868]. The Newall, not completed until 1869, was for several years the largest on Earth. It was built for a wealthy amateur who erected it at his private estate, but in 1890 was donated to Cambridge University.

Anders Jonas Ångström [b. Lögdö, Medelpad, Sweden, August 13, 1814, d. Uppsala, Sweden, June 21, 1874] discovers the element hydrogen in the spectrum of the Sun. *See also* 1858 AST; 1868 CHEM.

■ Biology

Karl Georg Friedrich Rudolf Leuckart [b. Helmstedt, Germany, October 7, 1822, d. Leipzig, Germany, February 6, 1898] publishes the first of his two volumes describing the parasites of human beings; volume two is published in 1876. *See also* 1877 MED.

Biochemist Ernst Felix Hoppe-Seyler [b. Freiburg-ander-Unstrut, Germany, December 26, 1825, d. Lake Constance, Bavaria, August 10, 1895] prepares a crystalline form of hemoglobin. *See also* 1904 MED.

Darwin's *The Various Contrivances by Which Orchids are Fertilized by Insects* shows how various parts of orchids' flowers have evolved to increase pollination by insects. *See also* 1859 BIO.

Naturalist Henry Walter Bates [b. Leicester, England, February 8, 1825, d. London, February 16, 1892] develops his theory of insect mimicry, based on color patterns of butterflies that he had studied during an 11-year stay in the jungles of South America. He argues that the mimicry by nonpoisonous insects of poisonous ones (now known as Batesian mimicry) cannot be explained by Lamarck's theories, which contributes to the acceptance of Darwin's and Alfred Wal-

lace's theory of evolution. *See also* 1915 BIO.

Systematic biologist George Bentham [b. England, September 22, 1800, d. September 10, 1884] publishes the first of three volumes of *Genera plantarum ad exemplaria imprimis in herbariis Kewensibus servata definita* ("genera of plants in the herbarium of the Kew botanical gardens," last volume 1883). This is his major work, based not only on his studies at Kew gardens, but also on many other taxonomic publications concerning plants in Spain, Britain, Hong Kong, Australia, and numerous other locations. His system of plant classification is the basis of modern plant taxonomy also.

□ Chemistry

Alexandre-Emile Beguyer de Chancourtois [b. Paris, January 20, 1820, d. Paris, November 14, 1886] develops an early version of the periodic table of the elements, but his work is poorly understood until after Mendeléev's table becomes known. *See also* 1829 CHEM; 1869 CHEM.

Alexander Mikhailovich Butlerov proposes that carbon's four valence bonds may have a tetrahedral arrangement, later established by Jacobus Henricus van't Hoff. *See also* 1857 CHEM; 1874 CHEM.

Earth science

William Thomson (Lord Kelvin) begins a five-year period of reassessment of the age of Earth based on thermodynamical considerations. He sets the range between 20,000,000 and 400,000,000 years. *See also* 1846 EAR; 1899 EAR.

Energy

John T. Allen demonstrates at the London International Exhibition a high-speed horizontal steam engine. Its speed is double that of the other engines of his time and sets an example for the further trend toward high-speed engines. *See also* 1849 ENER; 1866 ENER.

A lighthouse in the Straits of Dover uses an arc lamp powered by an electric generator, the first practical application of the generator. *See also* 1853 ENER; 1878 ENER.

Materials

Alfred Bernhard Nobel [b. Stockholm, Sweden, October 21, 1833, d. San Remo, Italy, December 10, 1896] begins experimenting with nitroglycerin, resulting in his invention of a patentable percussive detonator in 1863. *See also* 1867 MATR.

Pierre-Eugène-Marcelin Berthelot [b. Paris, October 27, 1827, d. Paris, March 18, 1907] repeats Marcel Moren's experiments with carbon electrodes in hydrogen gas, but recognizes acetylene, which had been produced as early as 1836 by Edmund Davy. Berthelot obtains credit for discovery of the method. *See also* 1859 MATR; 1897 CHEM.

Alexander Parkes displays at an international exhibition in London many items made

from what will come to be known as celluloid, a plastic on which he had been working throughout the 1850s. *See also* 1855 MATR; 1868 MATR.

Medicine & health

Alexander Pagenstecher introduces the use of yellow mercury oxide salve as an ophthalmologic ointment. *See also* 1851 MED; 1864 MED.

Tools

In November Richard Jordan Gatling [b. Maney's Neck, North Carolina, September 12, 1818, d. New York, February 26, 1903] develops the first machine gun. *See also* 1884 TOOL.

W.B. Bement introduces the first vertical milling machine, which makes it easy to cut dies to use in die stamping. This leads to die stamping becoming one of the main inexpensive manufacturing systems. *See also* 1861 TOOL.

Pierre Michaux patents the ball bearing in France. Ball bearings are first used in 1879 on bicycles. *See also* 1839 MATR.

Transportation

In the American Civil War, on March 9, the North's ironclad *Monitor* defeats but does not sink the Confederate ironclad *Merrimac* in the first naval engagement between ironclad ships. The *Merrimac* is a previously scuttled warship, raised and renamed the *Virginia* after getting its 10-cm (4-in.) iron plate. On the previous day the *Merrimac/Virginia* had sunk one and bullied two Union wooden-clad ships. *See also* 1861 TRAN.

1863

Anthropology

Sir Charles Lyell's *Geological Evidence of the Antiquity of Man* argues for the existence of early humans, based on the evidence of stone tools found in various ancient deposits. *See also* 1834 ARCH; 1864 ANTH.

Astronomy

Sir William Huggins [b. London, February 7, 1824, d. London, May 12, 1910] discovers the dark-line spectra of stars and shows that the same elements exist in the stars as on Earth. This disproves the Greek idea that the stars are composed of something different from Earth. *See also* 1835 AST.

Hubert Newton [b. 1830, d. 1896] correctly explains the Leonid meteor showers that are much more powerful at 33-year intervals. They occur when Earth passes through debris left in the orbit of a comet. *See also* 1833 AST.

Friedrich Argelander founds the first international organization of astronomers, the Astronomische Gesellschaft.

Biology

Thomas Huxley's *Evidence on Man's Place in Nature* is published. It is the first attempt by any scientist to apply Darwin's theories of evolution and natural selection to human beings. It emphasizes the ways in which apes and humans are similar. *See also* 1859 BIO; 1871 BIO.

Chemistry

Johannes Wislicenus [b. Klein-Eichsted, Germany, June 24, 1835, d. Leipzig, Germany,

December 5, 1902] discovers two isomers of lactic acid that differ only in the way they behave with regard to polarized light. He uses this difference a few years later to fight for an organic chemistry based on three-dimensional concepts of molecules. *See also* 1840 CHEM.

Ferdinand Reich [b. Bernburg (Germany), February 19, 1799, d. Freiberg, Germany, April 27, 1882] discovers what he thinks is a new element. Since he is colorblind, he asks his assistant, Hieronymus Theodor Richter [b. Dresden, Saxony, Germany, November 21, 1824, d. Freiberg, Germany, September 25, 1898], to examine its spectrum. Indeed, it is a new element, which the chemist names indium (In) for the indigo color of its spectrum. *See also* 1861 CHEM.

John Alexander Newlands [b. London, November 26, 1837, d. London, July 29, 1898] on February 7 announces the "law of octaves," essentially an early version of the periodic table. His work is met with derision. *See also* 1862 CHEM; 1869 CHEM.

Communication

Italian physicist Giovanni Caselli [b. Siena, Italy, 1815, d. Florence, 1897] patents his apparatus for the transmission of facsimile, the pantelegraph, in the United States. Developed between 1857 and 1865, the pantelegraph is based on earlier ideas of Alexander Bain and Frederick Bakewell and consists of two synchronized pendulums to which metallic pointers are attached. One pendulum is used to encode a handwritten message written on a metal plate with nonconducting ink. The message is

reproduced by the second pendulum at a distance on paper treated with prussiate of potassium. The pantograph operates between Paris and Lyon from May 16, 1865 to 1870 with another branch between Paris and Marseilles starting in 1867. War in 1870 will end the service, which will never be restored. *See also* 1847 COMM.

The National Academy of Sciences is founded in the United States.

Earth science

Meteorographica by Francis Galton introduces the term *anticyclone* to describe the large clockwise wind patterns of the Northern Hemisphere and introduces the modern method of mapping the weather. *See also* 1869 EAR.

Energy

Samuel Van Syckel builds an

11-km (7-mi) pipeline with a 5-cm (2-in.) diameter between his oil production plant and a railway station in Pennsylvania. It is the first known pipeline. *See also* 1860 ENER; 1872 ENER.

Food & agriculture

Louis Pasteur discovers the microorganism that sours wine and turns it into vinegar. He introduces heating to kill such microorganisms, a process that comes to be

known as pasteurization. *See also* 1956 BIO; 1865 BIO.

Materials

German chemist Joseph Wilbrand invents the explosive trinitrotoluene, better known as TNT. *See also* 1846 MATR.

Pierre-Emile Martin [b. Bourges, France, August 18, 1824, d. Fourchambault, France, May 24, 1915] succeeds in producing steel by heating a combination of steel

scrap and iron ore with gas burners. *See also* 1856 MATR.

Medicine & health

Adolf von Baeyer develops the first barbiturate.

Physiologist Etienne-Jules Marey [b. Beaune, France, March 5, 1830, d. Paris, May 15, 1904] invents the sphygmograph, the predecessor of the sphygmometer used to measure blood pressure today. *See also* 1847 MED.

(Johann Friedrich) Adolf von Baeyer

[b. Berlin, October 31, 1835, d. Starnberg, Germany, August 20, 1917]

Baeyer synthesized his first chemical at age 12 and then for his 13th birthday bought himself a lump of indigo dye to study; but he was nearly 30 before becoming the first to analyze the dye and synthesize it. Baeyer's other famous achievement was the creation of the first barbiturate (named for his then-girlfriend Barbara). Baeyer was the preeminent organic chemist of his day, working with many compounds and developing a still effective theory of chemical stability.



A chemist revolutionizes medicine

Louis Pasteur's career began by solving the outstanding problem in chemistry of his day: Why did two substances that were the same chemically react differently to light? His work for his doctoral degree, when he was only 26, led to the understanding that crystals can exist in right-handed and left-handed forms, a finding with implications that are still being worked out today. In this, as in many other enterprises, luck in choice of materials helped Pasteur. Of course, it was not fortune alone that made him a great scientist. As he said himself, "Chance favors the prepared mind."

Pasteur became the dean of chemistry at the French University of Lille in 1854. In 1856 an industrialist asked Pasteur to investigate why beer and wine often turn sour when aging. Leading chemists of the time, such as Justus Liebig and Friedrich Wöhler, believed that fermentation is a chemical reaction. Pasteur showed that both fermentation and spoiling are caused by minute living organisms. Pasteur also developed a way to prevent

wine from spoiling, in a process now called pasteurization. Heating wine to about 50°C (120°F) kills microorganisms that might spoil it.

Pasteur proceeded to study interactions of microorganisms and other organic materials. He showed, for example, that boiled meat extract does not spoil unless exposed to dust particles in air. In 1865 Pasteur investigated a disease that was killing silkworms. He was not able to isolate the microorganism, but suggested killing the infected silkworms and starting up new cultures free of infection.

Pasteur had recognized that infectious diseases are caused by microorganisms. This concept soon led others to introduce sterilization, disinfection, vaccines, and eventually antibiotics.

Pasteur himself developed several vaccines, including those for rabies and anthrax. He created weakened microorganisms by heating them. They could not cause the disease but evoked immunity to these germs in patients. His work was crowned by the successful inoculation of a boy bitten by a rabid dog in 1885.



Ernst Mach

[b. Chirlitz-Turas, Moravia (Czech Republic), February 18, 1838, d. Vaterstetten, Germany, February 19, 1916]

Mach's name, used to describe the ratio of the speed of an object to the speed of sound, is better known than his work, which largely concerned the philosophy of science. In 1929 the system of Mach numbers for speed was introduced, commemorating Mach's 1887 discovery that air flow changes dramatically above the speed of sound (Mach 1). Mach's philosophy, which heavily influenced both Einstein and the founders of quantum mechanics, is based on using directly observed phenomena as the only basis of science.

❖ Physics

Heat as a Mode of Motion by John Tyndall [b. Leighinbridge, Ireland, August 2, 1820, d. Hindhead, England, December 4, 1893] popularizes James Clerk Maxwell's theory of heat as the motion of molecules. *See also* 1860 PHY.

In *Die Mechanik* ("mechanics") Austrian physicist Ernst Mach introduces into physics the concept that a body would have no inertia if there were no matter in the universe, now known as Mach's principle. It will influence the development of general relativity theory. *See also* 1915 PHY.

I Tools

Jean Jacques Farcot develops a mechanism for controlling the rudder of a ship from the bridge by way of a hydraulic linkage. He terms this type of device, in which the linkage is an intermediate control, a "servomechanism." *See also* 1853 TOOL.

The first fire extinguisher patent is issued to Alanson Crane on February 11. *See also* 1866 ENER.

→ Transportation

Jean Lenoir builds the first "horseless carriage" that uses

an internal combustion engine for power (previous versions used steam engines). It can reach a speed of 5 km (3 mi) per hour. *See also* 1860 TRAN; 1878 ENER.

The first underground railways in London start operation; during the first year about 10,000,000 million people travel on the system. *See also* 1857 TRAN. 1868 TRAN.

Gabriel de la Landelle combines the Latin roots *avis* (bird) and *actio* (action) to obtain the new English word *aviation* to describe things connected with flight. *See also* 1889 TRAN.

1864

◀ Anthropology

Paleontologist Edouard Armand Isidore Hippolyte Lartet [b. Saint Guiraud, France, April 15, 1801, d. Seissan, Haute Garonne, France, January 28, 1871] about this time discovers an engraving of a mammoth on a piece of mammoth ivory found in the La Madeleine rock shelter in southwestern France. It is the first indication to science that people from the Ice Age practiced art. It also establishes for the first time that humans and

mammoths were alive on Earth at the same time since it is clear that whoever engraved the tooth had actually seen a live mammoth. *See also* 1863 ANTH.

★ Astronomy

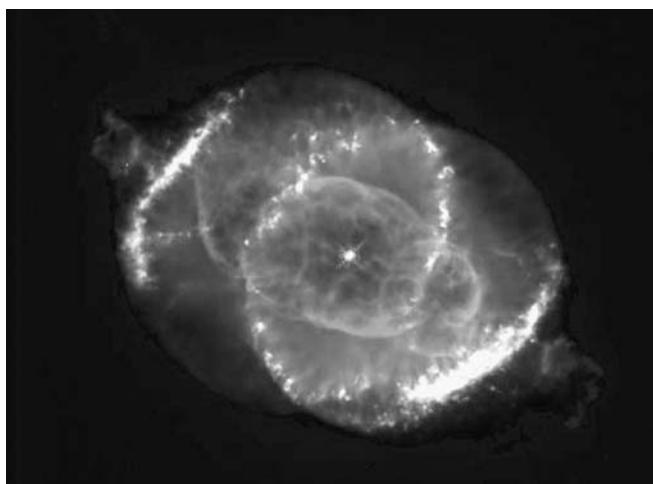
Sir William Huggins demonstrates that bright nebulae, such as NGC 6543 in Draco, consist of glowing gas since they display a bright-line spectrum (instead of the con-

tinuous spectrum with dark lines of stars). *See also* 1863 AST.

John Herschel publishes a catalog of nebulae and star clusters that contains more than 5000 items, based on his and his father William's observations. *See also* 1764 AST.

Giovanni Battista Donati [b. Pisa (Italy), December 16, 1826, d. Florence, September 20, 1873] makes the first spectroscopic examination of a comet, Tempel's comet, demonstrating that near the Sun the comet begins to radiate light while farther from the Sun it only reflects light. *See also* 1577 AST.

Astronomers agree on 147,000,000 km (91,000,000 mi) as the Sun's distance from Earth. The presently accepted value for the mean distance is 149,600,000 km (92,960,000 mi).



THE CAT'S-EYE NEBULA — NGC 6543 The planetary nebula NGC 6543, like all planetary nebulae, consists of glowing gas expelled by a dying star. This image from the *Hubble Space Telescope* shows the star at the center of the glowing gas — energy from the star makes the gas glow by a process similar to that in a fluorescent lamp. Such a glow produces a bright-line spectrogram. Stars, including the Sun, produce a full spectrum interrupted by dark lines where the outer gases of the stars absorb light.

Field theories

Early theories of motion, such as Aristotle's, assumed that some physical object must push or pull on another to cause motion. The ancient Greeks and others were aware of exceptions to this hypothesis, since they knew of magnets and static electricity. In both cases, objects move without any apparent contact — action at a distance.

In the first Scientific Revolution of the 16th and 17th centuries, the problem of action at a distance was "solved" by postulating various subtle media through which the action is transmitted. Generically, these are called aethers or ethers. The spelling *aether* is preferred for the whole class, while *ether* is generally used for the aether of electromagnetism. Different scientists postulated different aethers as needed, so there was an aether for heat, another for gravity, another for the magnetic force, and so forth — although Newton's theory of gravity really involved action at a distance, since Newton made no hypotheses as to how gravitational force was transmitted.

Michael Faraday was not satisfied with the theory of the aethers. He had observed the indications of lines of force that can be made visible by the effect of a magnet on iron filings. Similar lines can also be detected in three dimensions by carefully moving a compass near a magnet.

Faraday pictured these lines of force as thin tubes reaching from one pole of a magnet to another. He used these lines of force as a device to explain various magnetic phenomena that he discovered. By 1845 Faraday had developed evidence that suggested that the same concept could be used to explain the actions caused by static and current electricity and could even explain light.

Mathematically, Faraday's idea corresponds to assigning a number and a direction to every point in space. When you move a freely suspended compass near a magnet, the needle will tend to point in a particular direction and the amount of force on the compass will be a definite positive or negative number (depending on which pole you are approaching). Such an array of numbers and directions pervading space is called a *field*. Some fields, however, have just an amount (and no direction) at each location. These are called scalar fields.

In the 1860s James Clerk Maxwell used the mathematical rep-

resentation of Faraday's lines of force to explain light in terms of electric and magnetic fields. The two fields are bound together in this way: When a magnet moves, it introduces an electric current; when an electric current flows, it induces magnetism. Maxwell's equations show that this interaction of electricity and magnetism produces waves that propagate through space. He identified these waves as light waves.

Maxwell's equations implied that waves longer and shorter than those of light could be produced by moving electric currents. The existence of such waves was confirmed in 1888 when Heinrich Hertz used this method to produce radio waves. Infrared radiation was also explained as electromagnetic waves and accounts for the transmission of heat through space. Thus, one result of Maxwell's field theory was the unification of the various aethers into a single ether that was believed to transmit electromagnetic waves.

Maxwell next turned to gravity. He thought he could develop a field theory of gravity, since each point in space can have a number and a direction assigned to it to represent the total effect of gravitational forces on it. The number is always positive, however, which makes it very difficult to see how such a gravitational field would resemble an electric or a magnetic field, both of which have opposing forces — attraction (+) and repulsion (-). Maxwell abandoned the effort. Einstein solved the problem of describing the gravitational field in 1915, although the mathematical difficulties continue to be immense.

Einstein and others thought that there must be a single field theory that would include both electromagnetism and gravity. Einstein tried to develop such a unified field theory for many years, but was ultimately unsuccessful. In more recent years, various attempts at a theory of everything, such as supersymmetry or brane theory, have come closer to solving this problem, but none has won widespread acceptance because all are difficult to confirm experimentally.

Meanwhile, particle physicists discovered fields. Certain specialized types of field (gauge fields and Yang-Mills fields) seem to underlie all known particles, which appear as manifestations of the underlying field. Mass is thought to arise from one of these specialized fields, called a Higgs field, so physicists believe that they will someday find a Higgs particle.

Chemistry

On March 11 Cato Maximilian Guldberg [b. Christiana (Oslo), Norway, August 11, 1836, d. Christiania, January 14, 1902] and Peter Waage [b. Flekkefjord, Norway, June 29, 1833, d. Oslo, January 13, 1900] publish the law of mass

action: A reaction is dependent both on the mass and the volume of the constituents.

Communication

B.J. Sayce and William Blanchard Bolton introduce the use of silver bromide emul-

sion to photography. *See also* 1851 COMM; 1871 COMM.

Mathematics

"Linear Associative Algebra" by Benjamin Peirce [b. Salem, Massachusetts, April 4, 1809, d. October 6, 1880] is read to the American Association for

the Advancement of Science. It is best known for its opening sentence: "Mathematics is the science which draws necessary conclusions."

Medicine & health

Franciscus Donders rediscovers that astigmatism is caused

by an uneven curvature of the lens or cornea of the eye. *See also* 1801 MED.

New York dentist Sanford Christi Barnum [b. 1836, d. 1885] invents the rubber dam for controlling saliva while working on teeth. *See also* 1860 MED.

❖ Physics

James Clerk Maxwell's *A Dynamical Theory of the Electromagnetic Field* is the first of his publications to use Michael Faraday's concept of a field as the basis of a mathematical treatment of electricity and magnetism and introduces Maxwell's equations to describe electromagnetism. *See also* 1845 PHY; 1873 PHY.

I Tools

Norwegian whaling engineer Sven Foyn [b. Tønsberg (Norway), July 9, 1809, d. Ramdal (Norway), November 29, 1894] invents a gun for firing harpoons with explosive heads. The gun enables hunting the elusive fin, sei, and blue whales. *See also* 1890 FOOD.

Brown and Sharpe in Providence, Rhode Island, develops the first commercial grinding machine.

American manufacturer William Sellars [b. Delaware City, Pennsylvania, September 19, 1824, d. 1905] develops a standard screw thread that, especially in the United States, replaces the English standard of Joseph Whitworth. *See also* 1841 TOOL.

William Cotton of Loughborough, England, patents a knitting machine for hosiery that produces complete stockings sewn up in the back. His

device becomes the basic type of knitting machine. *See also* 1816 TOOL.

❖ Transportation

George Mortimer Pullman [b. Brocton, New York, March 3, 1831, d. Chicago, October 19, 1897], working with Ben Field, builds the first of his line of sleeping cars, noted for their exceptional comfort. These cars become known as Pullman cars after the Pullman Palace Car Company is founded in 1867. *See also* 1840 TRAN; 1868 TRAN.

1865

★ Astronomy

Sir William Huggins demonstrates spectroscopically that light from M31 (the Andromeda Galaxy) comes from stars and not from clouds of gas, although other nebulae produce light that is characteristic of glowing gases. *See also* 1864 AST; 1914 AST.

❖ Biology

Gregor Mendel publishes his theories of genetics in the obscure *Transactions of the Brünn Natural History Society*. *See also* 1860 BIO; 1900 BIO.

Hybridization experiments by Charles Victor Naudin [b. Autun, France, August 14, 1815, d. Antibes, France, April 19, 1899] show him certain regularities in the inheritance of characteristics in plants. *See also* 1860 BIO; 1900 BIO.

German botanist Julius von Sachs [b. Breslau (Wrocław, Poland), October 2, 1832, d. Würzburg, Germany, May 29, 1897] discovers that chlorophyll in plants is found only in small bodies (later termed chloroplasts) and that chloro-

phyll is the key compound in combining carbon dioxide and oxygen to produce starch while releasing oxygen. *See also* 1837 BIO.

Louis Pasteur is summoned to Alais in southern France to investigate a disease that is killing the silkworms there. He stops the spread of the disease by having infected silkworms killed and removed from contact with the healthy ones. *See also* 1835 BIO; 1876 BIO.

◊ Chemistry

Friedrich Kekulé describes the correct structural formula for benzene as a ring formed of six carbon atoms, establishing that organic molecules can form rings or other complex forms. His inspiration for the formula was a dream in which a snake swallows its tail. *See also* 1825 CHEM; 1882 CHEM.

Jean Servais Stas [b. Louvain, Belgium, August 21, 1813, d. Brussels, Belgium, December 13, 1891] produces the first modern table of atomic weights, using oxygen as a standard (set at 16). He shows conclusively that atomic weights are not always integral. The practice of using 16 for oxygen as a reference point will continue well into the 20th century, when chemists return to basing atomic masses on carbon-12. *See also* 1920 PHY.

II Food & agriculture

Edmund La Croix designs the first modern version of a middlings purifier, a device that removes bran from wheat flour. His device combines vibrating screens, similar to those proposed by Ramelli in 1588, and a current of air to lift the bran. *See also* 1588 FOOD.

Karl von Voit shows that the pathways by which food is converted to energy are complicated; food is not simply burned to produce energy; many intermediate reactions take place instead. *See also* 1861 MED.

◊ Materials

John Davison Rockefeller [b. Richford, New York, July 8, 1839, d. Ormond Beach, Florida, May 23, 1937] founds in Cleveland the first large oil refinery. *See also* 1859 ENER.

Σ Mathematics

August Ferdinand Möbius presents his discovery of a figure that has only one side and one edge, now called the Möbius strip. A model of it is made simply, by giving a strip of paper a half turn and then gluing the ends together. *See also* 1882 MATH.

About this time Karl Weierstrass proves the Bolzano-Weierstrass theorem: Every bounded infinite set of points in a Euclidean space has at least one point for which every neighborhood of that point contains a point in the set (that is, there is an accumulation point), proved earlier by Bernhard Bolzano. This will become the basis of the modern theory underlying limits. *See also* 1872 MATH.

♥ Medicine & health

English surgeon Joseph Baron Lister [b. Upton, England, April 5, 1827, d. Walmer, Kent, England, February 10, 1912] introduces phenol as a disinfectant in surgery, reducing the surgical death rate from 45 percent to 15 percent. *See also* 1847 MED.

Organic chemistry

Chemists often heat substances to see what will happen. Some solids melt; other solids and some liquids vaporize. If the liquid or vapor is trapped and the heat lowered, the same material comes back. But some substances burn, char, or coagulate. After that happens, cooling will not bring back the original substance. For the most part, this second class of materials can be recognized as products of living creatures, while the class that only melts includes metals and other items produced from the earth. In 1807 Jöns Jakob Berzelius named the first class — those that melt — inorganic and the second — those that burn — organic.

Although it was known that new chemicals could be produced from organic sources — Pierre-Eugene-Marcelin Berthelot made the first of these synthetics as early as 1778 — it was widely believed at the beginning of the 19th century that organic chemicals could not be synthesized from inorganic ones. Consequently, Friedrich Wöhler was astonished when in 1828 he heated some ammonium cyanate, classed as inorganic, and got urea, an organic chemical. We now know that ammonium cyanate is not, strictly speaking, inorganic, but Wöhler generally gets the credit for the first synthesis from inorganic material. People were astounded in his time. The popular idea that some mysterious vital principle was in organic chemicals had been dealt a severe blow.

Even if the vitalists were wrong, it was clear that organic chemicals were very different in some ways from inorganic chemicals. For one thing, chemicals that seemed to be exactly the same behaved differently. Jean-Baptiste Biot observed in 1815 that tartaric acid produced by grapes polarized light, while seemingly the same acid produced in the laboratory did not polarize light — but both acids had the same chemicals in the same proportions, or the same chemical formula. Justus von Liebig and Wöhler in the 1820s analyzed various different organic compounds, finding several apparently different substances that had exactly the same chemical formulas. In 1830 Berzelius named such pairs of compounds *isomers*.

Louis Pasteur's first major project as a young chemist was to try to unravel the mystery of why the two varieties of tartaric acid behaved differently. He observed a tiny difference among the crystals of the type of tartaric acid that did not affect light. After painstakingly separating the crystals into two groups, he discovered that tartaric acid from one group of crystals polarized light just the way tartaric acid from grapes did. Tartaric acid from the other group also polarized light, but in the opposite direction. Pasteur correctly realized in 1844 that the two types of polarization cancelled each other out in the laboratory-made substance. He also understood that two different organic chemicals might have different properties and the same formula because the shape of the molecule might be different between the isomers.

In 1845 Adolph Wilhelm Hermann Kolbe became the first chemist to synthesize an organic compound (acetic acid) directly

from chemical elements. Shortly after, the concepts of valence and bonding were introduced into chemistry. Friedrich Kekulé began to use diagrams based on bonding in organic chemistry in 1861. Kekulé's diagrams showed that Pasteur was correct. The shape of an organic molecule determines its properties.

Even before a basic understanding of organic molecules developed, chemists were beginning to synthesize new organic compounds with important properties not available in inorganics. The first such synthetic, nitrocellulose, was found by accident by Christian Schönbein in 1846. Also known as guncotton, it was very explosive. Nitrocellulose was discovered when Schönbein's wife's apron, which he had used to wipe up a spilled mixture of acids, exploded and vanished in a puff of smoke. When others tried to manufacture guncotton in quantity, many were killed by premature explosions. Another synthetic discovered soon after guncotton, nitroglycerine, was only marginally safer. Eventually, however, both substances were tamed into cordite and dynamite. The modern age of high explosives was at hand.

Ten years after the discovery of nitrocellulose, a young Englishman accidentally started another industry. William Perkin was trying to synthesize quinine when he produced the first synthetic dye, which we know as mauve. Perkin got rich on mauve and then went on to synthesize other chemicals. In 1875 he started his second industry by creating the first synthetic perfume ingredient, coumarin.

Although Perkin was English, he was something of an anomaly, for most of the organic chemists of the second half of the 19th century were German. In fact, Perkin's chemistry teacher, August Wilhelm von Hofmann, was a German chemist teaching in England. Hofmann synthesized his first dye, magenta, in 1858. After he returned to Germany, Hofmann continued to work on dyes and developed a number of violets. Other chemists in Germany worked on synthesizing exact copies of natural dyes from easily available chemicals, obtaining a red called alizarin in 1869 and indigo in 1880. All of these dyes became the basis of an immense German chemical industry. They also had an impact on biology, for biologists discovered that coloring bacteria or other cells with dyes made previously invisible structures apparent.

Another group of organic chemicals got their start in England and the United States. In 1865 English chemist Alexander Parkes found a way to convert nitrocellulose to a nonexplosive (but still quite flammable) substance that we know as celluloid, the first plastic. This was improved on by American inventor John Wesley Hyatt, who was looking for a replacement for ivory billiard balls. In the 20th century, English and American chemists continued to dominate the plastics industry, creating rayon, Bakelite, nylon, Teflon, Lucite, and polyester, among other synthetics.

In the late 19th century and the early 20th, the raw materials for most of these synthetics were coal, water, and air. Later in the 20th century, petroleum replaced coal, for there are generally fewer steps in a chemical process that starts with petroleum.



THE MÖBIUS STRIP The true Möbius strip is a two-dimensional, one-sided surface embedded in three-dimensional space, but a paper model represents its surprising properties. If you draw a line down the middle of the strip, it eventually travels on what seems to be both sides of the paper before meeting itself. If you cut the paper strip along that line, the strip fails to separate into two pieces. (Try it.) Although the model seems like a toy, the concept is important to mathematicians studying the properties of different spaces.

Jean-Antoine Villeman [b. Prey, France, January 28, 1827, d. October 6, 1892] shows that tuberculosis is a contagious disease.

✿ Physics

Rudolf Clausius invents the term *entropy* to describe the degradation of energy in a closed system. *See also* 1850 ENER.

I Tools

Hermann P. Sprengel [b. Schillerslage, Germany, August 29, 1834, d. London, January 14, 1906] develops a pump that creates a vacuum sufficient for experiments with electric lamps. The vacuum is created by mercury drops falling down a tube; every drop carries some air along with it, gradually creating a vacuum in the tube. *See also* 1871 TOOL.

The Jennings Pedestal Vase Company installs the first known pay toilets, using Joseph Bramah's design, out-

side the Royal Exchange in London. The price is one penny, which remains immune to inflation for the next hundred years. *See also* 1778 CONS.

➤ Transportation

The novel *From the Earth to the Moon* by Jules Verne [b. Nantes, France, February 8, 1828, d. Amiens, France, March 24, 1905] depicts three scientists and a journalist being shot to the Moon from a great cannon situated at Cape Canaveral, Florida. *See also* 1969 TRAN.

1866

★ Astronomy

Astronomer Daniel Kirkwood [b. Harford County, Maryland, September 27, 1814, d. Riverside, California, June 11, 1895] shows that the influence of Jupiter's gravity causes gaps, now known as Kirkwood gaps, in the distribution of the orbits of asteroids.

Giovanni Virginio Schiaparelli [b. Savigliano (Italy), March 14, 1835, d. Milan, July 4, 1910] establishes that there is an association between some comets and meteor showers. Great Leonid meteor showers occur, as predicted by Hubert Newton in 1863. *See also* 1833 AST.

❖ Biology

Generelle Morphologie der Tiere ("general morphology of organisms") by Ernst Heinrich Philipp August Haeckel [b. Potsdam, Germany, February 16, 1834, d. Jena, Germany, August 8, 1919] popularizes the incorrect notion that ontology recapitulates phylogeny; that is, the embryo goes through all the stages of evolution from the beginning of life to the present species. *See also* 1858 BIO.

Ernst Haeckel proposes a third kingdom of organisms, Protista, to include all single-celled species. Today simpler single-celled and cell colony organisms are placed in the kingdoms of Monera and Archaea, while more complex single-celled organisms are still classed as protists and still retain their kingdom status. *See also* 1846 BIO; 1880 BIO.

Karl von Voit develops the basal metabolism test between this year and 1873. *See also* 1865 FOOD.

Max Schultze develops the duplicity theory of vision, based on his study of the retina of birds, which correctly proposes separate functions for the rod cells and cone cells in the retina. *See also* 1861 BIO.

▷ Chemistry

Austrian chemist Johann Joseph Loschmidt produces the first measurement of the

size of a molecule in a gas. Although this is different from there being the same number of molecules in an equal volume of gas (which Loschmidt recognized as well known), in German-speaking nations, the number of molecules in a gas is termed Loschmidt's number instead of Avogadro's number. *See also* 1860 CHEM; 1905 PHY.

☛ Communication

Businessman Cyrus West Field [b. Stockbridge, Massachusetts, November 30, 1819, d. New York, New York, July 12, 1892] succeeds in laying a telegraph cable across the Atlantic Ocean. *See also* 1858 COMM.

American dentist and pioneer in radiotelegraphy Mahlon Loomis [b. Oppenheim, New York, July 21, 1826, d. Terra Alta, West Virginia, October 13, 1886] sends telegraph messages over radio waves between two mountains in West Virginia, using aerials held in the air by kites. Because this experiment is conducted before radio waves are recognized, Loomis's method of communication is ignored by science. *See also* 1883 COMM.

⊕ Earth science

Othniel Charles Marsh [b. Lockport, New York, October 29, 1831, d. New Haven, Connecticut, March 18, 1899] is appointed professor of vertebrate paleontology at Yale University, the first such post at a U.S. university. From this position, Marsh directs many searches for fossils, especially those of dinosaurs, throughout the western United States. *See also* 1870 EAR.

Gabriel-August Daubrée [b. Metz, France, June 25, 1814, d.

Paris, May 29, 1896] suggests that the center of Earth is a core of iron and nickel. *See also* 1906 EAR.

❖ Ecology & the environment

Ernst Haeckel introduces the word *ecology* (spelled *Oecologie* in German).

☛ Energy

French medical doctor François Carlier invents the chemical fire extinguisher. The extinguishing agent is a mixture of sodium bicarbonate and sulfuric acid, which forms a film that cuts off the fire's air supply. *See also* 1863 TOOL; 1905 MATR.

Charles Brown [b. 1827, d. 1905] and Heinrich Sulzer build a steam engine using superheated steam. Because superheated steam is too hot to condense on cylinder walls, its use increases the efficiency of steam engines. *See also* 1862 ENER; 1871 ENER.

Georges Leclanché [b. Paris, 1839, d. Paris, September 14, 1882] invents the zinc-carbon battery, a precursor to the dry cell and familiar "flashlight battery." *See also* 1859 ENER; 1887 ENER.

❖ Materials

The first known diamond to be found in southern Africa is picked up by a 15-year-old boy strolling along the Orange River. His discovery leads to Kimberly (Republic of South Africa) becoming the center of the world's greatest diamond-producing region.

Σ Mathematics

Nicolò Paganini, a 16-year-old schoolboy, startles mathematicians with his discovery of the

amicable pair 1184 and 1210; although many pairs of amicable numbers had been found in the 17th and 18th centuries, the pairs were all much larger, usually in the millions or billions. *See also* 1636 MATH.

John Venn [b. Hull, Yorkshire, England, August 4, 1834, d. Cambridge, England, April 4, 1923] writes *Logic of Chance*, which has a major influence on the later development of statistics. *See also* 1880 MATH.

♥ Medicine & health

Physician Sir Thomas Clifford Allbutt [b. Dewsbury, England, July 20, 1836, d. Cambridge, England, February 22, 1925] develops the clinical thermometer. Previously, thermometers used in medicine were too long for insertion into the body (they were tucked under armpits) and it took about 20 minutes to determine the temperature. *See also* 1850 MED.

Physician William Budd [b. North Tawton, Devon, England, September 14, 1811, d. Clevedon, Somerset, England, January 9, 1880] demonstrates that limiting the contamination of a town's water supply can stop a cholera epidemic (in Bristol, England). *See also* 1854 MED.

✳ Physics

August Adolph Eduard Eberhard Kundt [b. Schwerin, Germany, November 18, 1839, d. Israelsdorf, May 21, 1894] devises a method for measuring the speed of sound in different gases by analyzing patterns sound waves cause in a fine dust scattered inside a tube filled with the gas being investigated. *See also* 1809 PHY.

I Tools

Engineer Robert Whitehead [b. Lancashire, England, January 3, 1823, d. Beckett, England, November 14, 1905] invents the self-propelled torpedo, a bomb attached to a device that maintains a constant depth in water while using compressed air as a source of power.

U.S. inventor J. Osterhoudt develops a metal can that can be opened with a key that rolls up the top of the container (familiar to many as a method commonly used for canning various fish products).

1867

▲ Archaeology

Charles Warren [b. Bangor, Wales, February 7, 1840, d. Weston-super-Mare, England, January 21, 1927] discovers the vertical well in Jerusalem now known as Warren's Shaft. Later research suggests that it is a natural sinkhole that ancient Israelites converted into a well. *See also* 1980 ARCH.

★ Astronomy

Pietro Angelo Secchi [b. Reggio nell'Emilia (Italy), June 18, 1818, d. Rome, February 26, 1878] classifies the spectra of stars into four classes. Secchi completes the first spectroscopic survey of the stars, cataloging the spectrograms of about 4000 stars. *See also* 1911 AST.

❖ Biology

Paleontologist Edward Drinker Cope [b. Philadelphia, Pennsylvania, July 28, 1840, d. Philadelphia, April 12, 1897] proposes an alternative mechanism for evolution. Instead of natural selection,

he suggests that evolution proceeds as additional stages are added to the embryo—rather like "ontogeny recapitulates phylogeny," but using the developmental stages as a driving force instead of mere recapitulation. He also believes that use of particular body parts promote those being favored for further embryonic development, resulting in new species better adapted to the environment. *See also* 1859 BIO; 1870 EAR.

☛ Communication

The basis for what will become the first successful typewriter, the Remington Model I, is designed by Christopher Latham Sholes [b. Mooresburg, Pennsylvania, February 14, 1819, d. Milwaukee, Wisconsin, February 17, 1890], Carlos Glidden, and Samuel W. Soule and patented in 1868. *See also* 1714 COMM; 1872 COMM.

▀ Computers

Charles Sanders Peirce [b. Cambridge, Massachusetts, September 10, 1839, d. Milford, Pennsylvania, April 19, 1914] observes that Boolean algebra can be used to describe switching circuits, where ON and OFF replace TRUE and FALSE. *See also* 1854 COMP; 1938 COMP.

☛ Energy

Cromwell Varley rediscovers that an electric generator does not need to be started with an outside source of magnetism, but can use Earth's magnetic field to induce enough magnetism to get started. Sir Charles Wheatstone discovers the same independently and William von Siemens [b. Karl Wilhelm Siemens, Lenthe,

Hanover, Germany, April 4, 1823, knighted 1883, d. London, November 18, 1883] also announces discovery of the concept. Varley patents the idea, although it was probably originally discovered by Werner von Siemens, perhaps in 1866. *See also* 1857 ENER.

Belgian-French inventor Zénobe Théophile Gramme [b. Jehay-Bedognée, Belgium, April 4, 1826, d. Bois-Colombes, France, January 20, 1901] invents the ring arma-

ture and builds the first commercially practical generator for producing alternating current. *See also* 1857 ENER; 1871 ENER.

Nikolaus August Otto [b. Holzhausen, Germany, June 10, 1832, d. Cologne, Germany, January 26, 1891] and Eugen Langen [b. Cologne, 1833, d. 1895] develop an internal combustion engine that is an improved version of Lenoir's engine. *See also* 1862 ENER; 1870 ENER.

George Herman Babcock and Stephen Wilcox patent the Babcock Wilcox boiler, in which the steam generating tubes are placed in vertical rows over the grate and are connected to separation drums in which water is separated from the steam and recycled back. *See also* 1859 ENER.

Food & agriculture

Alphonso Dabb of Elizabethport, New Jersey, on April 2 receives the first U.S. patent

for a barbed fence attachment. Later in the year two other inventors receive patents for single-stranded wire fitted with barbs. *See also* 1860 FOOD; 1868 FOOD.

Materials

Joseph Monier [b. Gard, France, 1823, d. Paris, March 13, 1906], a gardener at the Versailles Palace, patents reinforced concrete and its use in concrete containers. *See also* 1824 MATR; 1877 MATR.

Perpetual motion: a 19th-century obsession

During the 19th century, with the advent of electricity, inventors planned and sometimes built machines in which an electric motor drove a generator that, in turn, supplied power to the electric motor. The goal was perpetual motion and a "free" source of energy. A large number of other designs, some very intricate and based on hydraulic, pneumatic, and magnetic forces, appeared at that time with the same purpose.

None of these machines fulfilled their promise. Some seemed to work, but invariably they were found to be hoaxes. Also during the 19th century, scientists discovered why perpetual motion machines would not work when they learned the law of conservation of energy.

Until then, the quest for free energy became comparable to the UFO obsession during the 20th century. Several inventors cashed in by building complicated machines and charging admission for demonstrations or receiving funding for their inventions. A famous case was that of Charles Redheffer, who, at the beginning of the 19th century, displayed a perpetual motion machine in his house in Philadelphia, Pennsylvania, charging admission fees and receiving funding. Redheffer was soon found out because a young boy noticed that the teeth on a cogwheel were worn on the wrong side, showing that the machine was driven by an external power source.

Redheffer promptly moved his show to New York City, where he was unmasked by the famous engineer Robert Fulton, who, upon seeing the machine, exclaimed, "Why, this is a crank

motion!" Fulton had noticed an irregularity in the rotation of the machine, the telltale sign of a manually driven crank.

But some perpetual motion machines were bona fide attempts at extracting energy from the forces of nature. The Zeromotor was a famous project of a British professor, John Gamgee. His idea was based on replacing water in a steam engine with ammonia, a liquid that boils at -433.5°C (-31.9°F). He reasoned that the ambient heat would cause the ammonia to boil. Even at a temperature as low as 0°C (32°F), boiling ammonia turns to a gas that increases in volume enough to produce 4 atmospheres of pressure, sufficient to drive a piston in a cylinder. During expansion in the cylinder, Gamgee believed, the ammonia gas would condense and the resulting liquid could be pumped back to the "boiler."

In practice, the gas did not liquefy, and the Zeromotor did not work. What Gamgee had overlooked was that the ammonia gas would condense only if the cylinder had cooled below the boiling point of ammonia, back below to -33.5°C . Unfortunately, the energy required to cool the cylinder would be greater than the amount the machine could supply. Just as in all other perpetual motion machines, there was a hitch. As in most such cases, the hitch was the second law of thermodynamics, the rule that heat always flows from warmer places to cooler ones unless some outside energy is applied to reverse the flow. A version of this law discovered by the French engineer Sadi Carnot in 1824 is that the most energy available from a process is fixed by differences in heat energy.

Understanding of the laws of thermodynamics made it clear to scientists that a machine that can supply power from nothing is a physical impossibility. Notwithstanding, intrepid inventors are still building perpetual motion machines today.

Alfred Nobel patents dynamite in Great Britain, an explosive based on nitroglycerine but mixed with other compounds to make it safer in use; he is granted a U.S. patent in 1868. *See also* 1862 MATR; 1875 MATR.

❖ Physics

William Thomson (Lord Kelvin) proposes a vortex model of the atom to Hermann von Helmholtz in a letter dated January 22. This model remains popular with many scientists for about 20 years, and then is abandoned. *See also* 1904 PHY.

I Tools

The friction tube, which uses percussion powder that is set off by drawing a rough bar through the powder to ignite a cannon's charge, is invented. *See also* 1845 TOOL.

✈ Transportation

American engineer George Westinghouse [b. Central Bridge, New York, October 6, 1846, d. New York, March 12, 1914] solves a major problem of the railways by inventing the air brake. It allows the simultaneous braking of cars on a train; previously, brakes had to be applied manually on each car. *See also* 1902 TRAN.

British marine engineer William Froude [b. Dartington, England, 1810, d. Simon's Town, South Africa, May 6, 1879] starts experimenting with model ships to study the hydrodynamic properties of hulls. He develops the Froude number, one of the basic concepts of fluid dynamics.

The automatic block system for railroads, which uses signals controlled by the passage

of trains to keep trains on the same track at the appropriate distance, is introduced in the United States. *See also* 1855 TRAN; 1871 TRAN.

Leon Francois Edoux [b. 1827, d. 1910] introduces the elevator driven by an expanding column operating under water pressure; such an elevator, traveling over 160 m (535 ft), will be installed in 1889 in the Eiffel Tower. *See also* 1860 TRAN.

1868

◀ Anthropology

Workmen building a road in France discover five skeletons in a cave named Cro-Magnon. The skeletons appear to be about 35,000 years old, giving rise to the name "Cro Magnon" for early *Homo sapiens*. *See also* 1856 ANTH; 1894 ANTH.

★ Astronomy

Sir William Huggins, using the spectrogram of the star, finds from the Doppler effect that Sirius is moving away from us. It is the first observation of a Doppler shift in the light from a star. *See also* 1848 PHY; 1888 AST.

Pierre Jules Cesar Janssen [b. Paris, February 22, 1824, d. Meudon, France, December 23, 1907] and Sir Joseph Norman Lockyer [b. Rugby, England, May 17, 1836, d. Salcombe Regis, Devonshire, England, August 16, 1920] independently describe a method for observing the solar prominences at times of noneclipse. *See also* 1860 AST.

Armand Fizeau proposes the use of interferometry for avoiding the effect of atmospheric turbulence. In his

design he puts a mask with two holes on the telescope objective and observes the superimposed images in the focal plane. *See also* 1974 AST.

❖ Biology

Zoologist Sir Charles Wyville Thomson [b. Bonsyde, Scotland, March 5, 1830, d. Bonsyde, March 10, 1882] starts deep-sea dredging operations, some as deep as 4390 m (2400 fathoms, or 14,400 ft). They reveal that there are many different forms of life at the bottom of the oceans. *See also* 1855 EAR; 1872 EAR.

Darwin's *The Variation of Animals and Plants under Domestication* is a detailed expansion of the subject treated in the first chapter of *The Origin of Species*. *See also* 1859 BIO; 1871 ANTH.

▷ Chemistry

Karl James Peter Graebe [b. Frankfurt-am-Main, Germany, February 24, 1841, d. Frankfurt-am-Main, January 19, 1927] discovers the structure of the molecule of alizarin, an important natural dye. Knowledge of the structure is the key to synthesizing the dye from coal tar, which is accomplished the following year. William Perkin, independently from Graebe, also determines alizarin's structure. *See also* 1831 MATR; 1869 CHEM.

While observing an eclipse of the Sun, Pierre-Jules-Cesar Janssen observes a line in the Sun's spectrum that does not belong to any known element. He sends a copy of the spectrum to Sir Joseph Lockyer, who confirms that it is a new element. Lockyer names the element helium (He), which

means "element of the Sun." *See also* 1862 AST.

⌚ Communication

A pneumatic mail system is installed in Paris. The system will operate for over 100 years and the tubes will extend to more than 400 km (250 mi). *See also* 1859 COMM.

⊕ Earth science

A violent earthquake accompanies repeated eruptions of Mauna Loa and Kilauea, killing more than 100 and resulting in a fundamental change in the type of lava produced by Mauna Loa. *See also* 1815 EAR; 1883 EAR.

🍴 Food & agriculture

Hippolyte Megé-Mouriés [b. Draguignan, France, October 24, 1817, d. May 31, 1880] wins a competition for a substitute for butter with the first blended margarine, an oil-in-water emulsion of fats.

William Perkin synthesizes coumarin, a scent and flavoring used in foods until 1954, when it is discovered to cause liver poisoning.

Michael Kelly of New York City becomes the first to patent double-stranded barbed wire, although his method fails to provide a way to keep the barbs in place. *See also* 1867 FOOD; 1874 FOOD.

James Oliver [b. Whitehaugh, Scotland, August 28, 1823, d. South Bend, Indiana, March 2, 1908] develops a process for producing chilled cast iron that revolutionizes plow making. *See also* 1837 FOOD.

◊ Materials

William von Siemens and his brother Friedrich develop the open hearth process for mak-

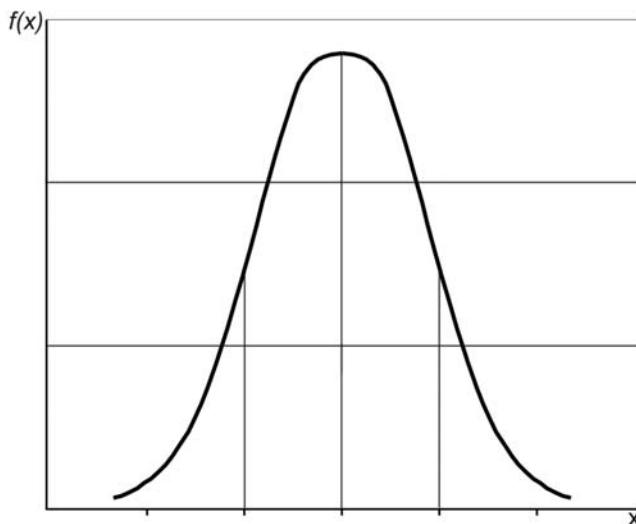
1868–1869

ing steel that after a time supersedes the Bessemer process. By 1950 about 85 percent of plain steel is made by the open hearth process, but thereafter newer methods begin to take over. *See also* 1856 MATR.

Daniel Spill in England invents the synthetic plastic trademarked Xylonite, a mixture of pyroxylin (a lower-nitrated cellulose nitrate), alcohol, and ether. It is considered a precursor to the similar plastic trademarked Celluloid that is invented about the same time. *See also* 1862 MATR; 1869 MATR.

Σ Mathematics

Saggio de interpretazione della geometria non-Euclidea ("essay on the interpretation of non-Euclidean geometry") by Eugenio Beltrami [b. Cremona (Italy), November 16, 1835, d. Rome, February 18, 1900] shows that non-Euclidean geometry is consistent if Euclidean geometry is consistent. His method is to give a different meaning to the word "line" in such a way that non-Euclidean geometry (with that meaning of line) can be modeled as part of Euclidean geometry. *See also* 1854 MATH; 1899 MATH.



THE BELL-SHAPED CURVE OF THE NORMAL DISTRIBUTION Mathematically, the bell-shaped normal curve appears as the limit when measurements of some trait (such as height or intelligence) are plotted along the horizontal axis while the number of individuals with a particular measure is represented as the height above that axis. The vertical lines on both sides of the line to the peak represent a distance of one standard deviation from the central value. An empirical rule is that about 68 percent of all measurements fall within a standard deviation of the central value.

▼ Medicine & health

Francis Galton shows that mental abilities of human beings form a normal distribution, lying along the familiar bell-shaped curve. *See also* 1861 MED.

I Tools

Thomas Alva Edison patents his first invention, a device to

record votes in Congress developed with the intent of speeding up proceedings. *See also* 1870 TOOL.

Charles Henry Gould invents the wire stitcher for use in binding magazines. The machine takes an uncut piece of wire and cuts, inserts it in the fold of a magazine, and folds the wire ends over. Such

a stitcher, the predecessor of the modern stapler, can only work parallel to a fold and cannot insert its "staples" close together. *See also* 1877 TOOL.

James Clerk Maxwell, in an article on the governor, introduces the concept of "feed back," that is, the information sent back to a system to effect a correction or change.

→ Transportation

The first underground railways (subways) in New York City start operation. *See also* 1863 TRAN.

1869

★ Astronomy

Charles Augustus Young [b. Hanover, New Hampshire, December 15, 1834, d. Hanover, January 3, 1908], in studying the solar eclipse of this year and the eclipse of 1870, observes that the dark lines of the Sun's spectrum brighten just before totality. The ordinary dark-line spectrum (caused by gases in the solar atmosphere blocking frequencies of light) is briefly replaced by a bright-line spectrum (caused by the glowing gases of the outer atmosphere and corona).



Thomas Alva Edison

[b. Milan, Ohio, February 11, 1847, d. West Orange, New Jersey, October 18, 1931]

Edison was the most prolific inventor of all time, receiving 1093 patents in the United States alone and laying the groundwork for many technological innovations of the 20th century. His major inventions include the phonograph, introducing the idea of recording sound, and an incandescent lamp that had a carbon filament sealed in a glass globe containing a partial vacuum. Edison also planned the first electricity distribution system — with dynamos, insulated underground cables, meters for measuring consumption, outlets, and switches — to carry electricity to houses. In addition, Edison patented the first machine to produce motion pictures. Yet another major invention, the nickel-alkaline storage battery with lithium, came in 1908. Edison also discovered that heat causes an electric current to flow between his lamp's filament and a separate electrode inside the lamp — the Edison effect.

America's greatest inventor

Thomas Alva Edison is the most successful and well-known inventor of all time, with more than a thousand patents to his name. His best-known inventions are the incandescent lamp, the phonograph, and motion pictures, but he also contributed inventions for telegraph systems.

Others also invented some of the devices we associate with Edison, but he often made them better and he got people to use them. His success began with hard work; for example, he performed thousands of experiments to find a suitable filament that would resist the intense heat that results when producing light.

Another factor that made Edison a successful inventor was a keen interest in anything mechanical. As a teenager he worked as a telegraph operator and was repeatedly fired because of his constant tampering with the equipment.

Edison's success is often attributed to his business sense, but this is open to question. His first major patent, a vote recorder for Congress, did not rouse interest — one congressman told Edison that legislators wanted to keep voting records vague. Edison then vowed to make only inventions for which there was demand. Although correct about the electric light, his efforts with electric automobiles were superseded by the internal combustion engine. His list of possible applications for his phonograph included a dictating machine for letter writing, spoken books, teaching of speech, reproduction of music, archiving of voices of famous people, music boxes and toys, speaking clocks, study of language, educational recordings, and transmission of

recorded messages over the telephone. Not only is recording of music halfway down the list, but initially Edison resisted even the idea. Possibly, his partial deafness was a factor in his failure to recognize the importance of recorded music; in any case, all of his other ideas have come to pass, although nearly always using magnetic tape (or, more recently, digital and laser) technology instead of his purely mechanical method.

There are other examples of Edison's inability to foresee the uses to which his inventions might be put. He fought against projection for motion pictures, and believed that more money was to be made on peep shows than in movie houses. Consequently, although Edison showed that motion pictures were possible and made some of the early films, credit for the cinema outside of the United States is usually granted to the Lumière brothers of France, who projected motion pictures for small audiences from the first.

Where Edison's business acumen was more evident was in the development of manufacturing and distribution related to his inventions. The electric generator had been available for decades when Edison opened the first power plants in London and New York City. He correctly recognized that his light bulbs would be of no use unless electric power was available and that money was to be made not only by selling the bulbs, but also by supplying the electricity.

Edison was not much interested in science for its own sake. In 1883 he discovered the basic principle of the vacuum tube (or valve), still known as the Edison effect, but he paid no attention to something for which he failed to see a use.

Dmitri Ivanovich Mendeléev

[b. Tobol'sk, Russia, February 7, 1834, d. St. Petersburg, February 2, 1907]

In 1869 Mendeléev published the first effective version of the periodic table of the elements. Unknown to Mendeléev, five years earlier John Newlands had proposed a similar table based on strictly increasing atomic masses forming periods of eight elements. Mendeléev's table used valences as well as atomic masses, enabling him to recognize periods of 18 elements later in the table. Mendeléev was bold in predicting three new elements and their properties for his 1871 version of the table and in rearranging the order from that of atomic masses where needed to make properties fall in line. The three predicted elements were found by 1885, exactly as described, and the rearrangements were justified in 1913 by the discovery of atomic number.



Biology

Johann Frederick Miescher [b. Basel, Switzerland, August 13, 1844, d. Davos, Switzerland, August 26, 1895] discovers a chemical in the nucleus of cells that he calls nuclein, but he is discouraged from publishing his findings until 1871

because the idea that the nucleus is a chemical is so unexpected. See also 1879 BIO.

Père Armand David, a French missionary in China, is the first scientist to observe and describe the giant panda.

Nathanael Pringsheim [b.

Wziesko, Poland, November 30, 1823, d. Berlin, October 6, 1894] completes a 15-year-long study of algae with *Beobachtungen über die Paarung de Zoosporen*, which describes a primitive form of sexual reproduction employed by some algae. See also 1876 BIO.

Chemistry

Dmitri Mendeléev publishes his first version of the periodic table of elements on March 6. (Julius) Lothar Meyer [b. Varel, Germany, August 19, 1830, d. Tübingen, Württemberg, Germany, April 11, 1895] also develops a version of the peri-

odic table this year, but will not publish his summary of his work, "Die Natur der chemischen Elemente als Function ihrer Atomgewichte" ("the nature of the chemical elements as a function of their atomic weights"), until 1870. *See also* 1862 CHEM; 1871 CHEM.

In June German chemist Heinrich Caro [b. Posen (Poznán, Poland), February 13, 1834, d. Dresden, Germany, October 11, 1910] patents synthetic alizarin, the red dye naturally obtained from madder, one day before William Perkin applies for a patent on his development of the same dye. After learning earlier about synthesis of dyes from Perkin in England, Caro had returned to Germany to work for Badische Anilin- & Soda-Fabrik (BASF). He will come to lead the development of the German dye industry. *See also* 1868 CHEM.

Physical chemist Thomas Andrews discovers the critical temperature of a gas (independently from Mendeléev); above this temperature it is not possible to liquefy the gas by increasing pressure on it. *See also* 1880 PHY.

Communication

Publication of the scientific journal *Nature* begins.

Louis Ducos du Hauron and Charles Cros [b. Fabrezan, France, October 1, 1842, d. Paris, August 10, 1888] describe in *Les couleurs en photographie, solution du problème* ("colors in photography, the solution to the problem") the methods they have developed for recording a color image on a single photographic plate and projecting it with a single projector. They

also clearly state the additive and subtractive ways that different colors can be obtained. One method requires breaking the light from the projector and the image on the plate into tiny dots that are handled so as to produce separate dots of color on the screen, which the eye then combines. Another method proposes to produce color photographs by taking negative pictures through three color filters and then projecting them on three colored gelatin plates, which superimposed, would reconstitute the original colors; however, they do not succeed in reproducing true colors when the method is actually tried. *See also* 1861 COMM; 1873 COMM.

Construction

John Augustus Roebling designs and begins work on the Brooklyn Bridge between Brooklyn and Manhattan, New York, but dies as a result of an accident. When the bridge is completed by his son and his son's wife, it will be the longest suspension bridge built so far. *See also* 1855 CONS; 1883 CONS.

Earth science

On September 1 meteorologist Cleveland Abbe [b. New York, New York, December 3, 1838, d. Chevy Chase, Maryland, October 28, 1916] begins to send out weather bulletins from the Cincinnati observatory, where he is director. *See also* 1337 EAR; 1871 EAR.

Energy

Belgian-French inventor Zénobe Gramme builds the first commercially practical generator for producing direct current. *See also* 1867 ENER.

Food & agriculture

According to Forster Manufacturing, the commercial toothpick is invented by Charles Forster in his basement in Boston, Massachusetts.

Materials

John Wesley Hyatt [b. Starkey, New York, November 28, 1837, d. Short Hills, New Jersey, May 10, 1920] develops the substance trademarked in the United States as Celluloid, the first commercial artificial plastic, probably not quite independently of Alexander Parkes, who had produced the same substance or something close to it a few years earlier, or of Daniel Spill, who made a similar plastic; Hyatt uses his new plastic to win a \$10,000 prize for a substitute for ivory in billiard balls, and later commercializes the product as a base for film in photography. Essentially, Celluloid is the same cellulose nitrate as guncotton, but less nitrated and therefore not explosive (although still quite flammable). *See also* 1868 MATR; 1909 MATR.

Medicine & health

Physician Paul Langerhans [b. Berlin, July 25, 1847, d. Funchal, Madeira, Portugal, July 20, 1888] makes a careful dissection of the pancreas and discovers the small groups of cells now called the islets of Langerhans. Later it will be discovered that these groups of cells are the source of insulin. *See also* 1889 MED.

German surgeon Johann Friedrich August von Esmarch [b. Toenning, Germany, January 9, 1823, d. Kiel, Germany, February 23, 1908] demonstrates the use of a prepared

first-aid bandage on the battlefield. *See also* 1746 MED; 1877 MED.

Physics

John Tyndall discovers the effect named after him, namely that a beam of light passing through a colloidal solution can be observed from the side. *See also* 1850 CHEM.

Tools

In August Edison goes to work for a stock reporting company in New York City, where he improves the stock ticker, also known as a gold indicator, they have been using. In the fall he leaves to form his own company to manufacture his inventions. *See also* 1870 TOOL.

A large band saw is developed and patented by Jacob R. Hoffman and soon becomes the standard device for heavy sawing in the United States. *See also* 1814 TOOL.

Transportation

Ferdinand de Lesseps completes construction of the Suez Canal, linking the Mediterranean and Red seas. *See also* 1859 TRAN; 1880 TRAN.

Edward Everett Hale [b. Boston, April 3, 1822, d. Roxbury, Massachusetts, June 10, 1909] publishes *The Brick Moon*, about an artificial satellite placed in orbit as a navigational aid, reviving an idea not much discussed since the time of Isaac Newton. *See also* 1687 TRAN; 1957 TRAN.

On May 10 the Union Pacific and Central Pacific railroads hook up at Promontory Summit, Utah, as a golden spike is hammered to link the lines, creating the first transcontinental rail system in North America.



AMERICA'S FIRST TRANCONTINENTAL RAILROAD While the crews of the two locomotives celebrate, dignitaries from the Union Pacific and Central Pacific railroad lines, government officials, and local citizens line up to observe the ceremony of the golden spike — a large nail driven through the last railroad tie that binds together the eastern and western track lines. The symbolic golden spike was followed by an actual iron spike to secure the railroad tie.

André Guilmet and Meyer develop a bicycle in which the power from the pedals is transmitted to the back wheel by a chain. J.F. Tretz also uses a chain drive to propel the large front wheel of the popular bicycle called a “high wheeler,” so that people with short legs will not be at a disadvantage. *See also* 1861 TRAN; 1876 TRAN.

1870

▲ Archaeology

Heinrich Schliemann begins excavating a large mound near Hissarlik in Turkey, which he proposes is the site of Homer's Troy, a city-state known largely from the epic poems of Homer written about 800 BCE. *See also* 1873 ARCH.

Jules Oppert [b. Germany, 1825, d. 1925], while translating clay tablets excavated at Nineveh (Iraq), recognizes that the texts refer to a very ancient civilization in the Middle East, which he names

the Sumerians. *See also* 1845 ARCH; 1898 ARCH.

★ Astronomy

Lawrence Parsons, the fourth Earl of Rosse [b. November 17, 1840, d. 1908], measures the temperature of the Moon's

surface by detecting its infrared radiation. He estimates the Moon's sunlit surface to be 227°C (500°F). Current measurements indicate its temperature to be 267°C (540°F). *See also* 1856 AST.

★ Biology

Gustave Theodor Fritsch [b. Gottbus, Germany, March 5, 1838, d. Berlin, June 12, 1927] and Julius Eduard Hitzig [b. Berlin, February 6, 1838, d. Luisenheim zu St. Blasien, Germany, August 20, 1907] discover that the cerebral cortex has different compartments for different functions. They also introduce the study of the brain by electrical stimulation. *See also* 1861 MED; 1876 MED.

↳ Communication

James Clerk Maxwell proposes that all measurement standards be based on atoms because all atoms of a substance are thought to be exactly alike (a view later physicists will modify). Maxwell's idea is not put into practice until more than 100 years later, largely because physicists do not know enough about atoms to use them in this way until the 1960s. *See also* 1960 COMM.



(Johann Ludwig) Heinrich (Julius) Schliemann

[b. Neu Buckow, Mecklenburg-Schwerin, Germany, January 6, 1822, d. Naples, Italy, December 26, 1890]

Most scholars believed that Homer's Troy was a fictional place. But Schliemann believed it had actually existed and began to search for it. He argued that a large mound at Hissarlik, on the northwest coast of Turkey, was the site of Troy. He began digging in 1870, passing through upper layers of human habitation. In 1873 his team of workers conclusively reached the remains of Troy, uncovering fortifications, a paved road, a double gate, buildings, and a hoard of magnificent gold jewelry. As Schliemann carried out further excavations, he discovered even earlier settlements beneath Troy. Schliemann also uncovered other ancient sites associated with heroes described by Homer, including Mycenae, the city ruled by King Agamemnon, who led the Greeks against Troy.

⊕ Earth science

The famous feud between paleontologist Edward Drinker Cope and Othniel Charles Marsh of Yale University over dinosaurs in the American West begins with an argument over which end of a plesiosaur is its head and which its tail. Some believe that even earlier Marsh was paying Cope's fossil hunters to send their best finds to Marsh at Yale. *See also* 1867 EAR.

↗ Energy

Julius Hock in Vienna is the first to build an internal combustion engine that works on Lenoir's principle, but uses liquid gasoline instead of coal gas as fuel. *See also* 1867 ENER; 1877 ENER.

■ Food & agriculture

William Lyman of West Meriden, Connecticut, patents a can opener that uses a wheel for continuous operation, improving on the lever-and-chisel variety that had preceded it. The can must be pierced in the center of the lid and must be adjusted to fit each size can. *See also* 1858 FOOD; 1925 FOOD.

American photographer Thomas Adams [b. 1818, d. 1905] invents chewing gum. It is intended as a substitute for chewing tobacco.

Σ Mathematics

Traité des substitutions et des équations algébriques ("treatise on substitutions and algebraic equations") by (Marie Ennemond) Camille Jordan [b. Lyon, France, January 5, 1838, d. Paris, January 22, 1922] summarizes Jordan's work since 1860 with permutation groups, which makes the theory of finite groups one of the main themes of mathe-

matics. Previously, finite groups had occupied a few very specific roles. *See also* 1846 MATH; 1894 MATH.

I Tools

Edison improves his stock ticker or gold indicator from 1869 by making it possible to adjust remote indicators to match the home station. He sells the invention to a Wall Street firm for an often-quoted figure of \$40,000, a fortune at the time (although a preliminary letter of agreement from October 19 shows only \$30,000, still a substantial amount). *See also* 1869 TOOL.

→ Transportation

Germain Sommeiller's Mont Cenis Tunnel through the Alps, the first major railroad tunnel, is completed. Started in 1857, it is 14 km (8.7 mi) long. Both pneumatic drills and dynamite, new tools at the time, are used in its construction. *See also* 1858 TOOL.

1871

◀ Anthropology

Darwin's *The Descent of Man and Selection in Relation to Sex* discusses evidence of evolution of human beings from lower forms of life, comparing people to animals. He introduces the concept of sexual selection to explain human hairlessness and the concept of group selection to explain the human's lack of natural weapons, such as powerful teeth or claws. *See also* 1863 BIO; 1872 BIO.

↶ Biology

Ernst Felix Hoppe-Seyler discovers invertase, an enzyme that speeds conversion of sucrose into glucose and fructose. *See also* 1836 BIO; 1876 MED.

Anatomist Karl Gegenbaur [b. Würzburg, Germany, August 21, 1826, d. Heidelberg, Germany, June 14, 1903] shows that the theory that the skull arises from an expansion of the vertebrae cannot be true and that all vertebrate cells arise from divisions of the egg and sperm. *See also* 1848 BIO.

▷ Chemistry

Dmitri Mendeléev announces on January 7 that the gaps in his periodic table represent undiscovered elements. The gaps are filled by discoveries of new elements in 1875, 1879, and 1885, making Mendeléev famous. *See also* 1869 CHEM; 1875 CHEM.

Organic chemist Viktor Meyer [b. Berlin, September 8, 1848, d. Heidelberg, Germany, August 8, 1897] discovers that molecules of iodine and bromine, each of which contain two atoms, break up into single-atom molecules when heated.

↶ Communication

English physician Richard Leach Maddox [b. August 4, 1816, d. May 11, 1902] introduces the dry plate (bromide on gelatin) to photography. *See also* 1864 COMM; 1884 COMM.

⊕ Earth science

In January Cleveland Abbe becomes the scientific assistant in the Signal Corps of the U.S. army, where he heads the first version of a government weather-forecasting service. The salary makes him among the highest paid scientists in the United States. On February 19 he issues the first official weather forecast. *See also* 1869 EAR; 1891 EAR.

↗ Energy

Peter Brotherhood [b. 1838, d. 1902] patents a radial three-cylinder steam engine. The cylinders are placed at angles of 120 degrees and the connecting rods are linked to a common crank pin; since its invention, the Brotherhood engine has been used as an air motor for torpedoes and as an air compressor. *See also* 1866 TOOL.

■ Food & agriculture

Naturalist Luther Burbank [b. Lancaster, Massachusetts, March 7, 1849, d. Santa Rosa, California, April 11, 1926] develops the Burbank potato. In his career, he creates many new varieties of plums and berries, the Shasta daisy, and many other plant varieties, despite his belief in the inheritance of acquired characteristics, proved wrong many times over.

❖ Materials

Robert Mushet develops a very hard type of carbon steel by adding small amounts of tungsten and manganese; named Mushet steel, the alloy finds a wide application in machine tools.

German chemist Hermann Sprengel shows that the yellow dye picric acid can be detonated and is an effective explosive. *See also* 1771 CHEM; 1885 MATR.

Σ Mathematics

Felix Klein publishes the first of two monographs entitled *Über die Sonnenannte Nich-Euclidische Geometrie* ("on the so-called non-Euclidean geometry") that develop Euclidean models for various types of non-Euclidean geometries. The second is published in 1873. *See also* 1868 MATH.

The periodic table

In 1799 Joseph-Louis Proust established that the compound copper carbonate always has the same proportions of copper to carbon to oxygen by mass, no matter how the compound is prepared. He proceeded to carry out similar analyses of other compounds over the next ten years, showing that in every case the proportions of the elements by mass stayed constant for a given compound. John Dalton was the first to explain why Proust's law of definite proportions held true. Dalton postulated in 1800 that the chemical elements are made from atoms that differ largely by mass. If the mass of an atom of hydrogen, the lightest element, is taken as 1, then the other elements have atoms whose masses are multiples of hydrogen. Dalton tried to calculate these masses, but got in trouble because he was not sure of the exact atomic composition of compounds, such as water. In 1828, however, Jöns Jakob Berzelius published a list of atomic weights (weighted averages of atomic masses found in natural sources of an element) that was quite accurate. No one paid much attention to this idea at the time.

In 1860 Friedrich Kekulé reached the conclusion that chemistry was in chaos because different formulas were being used for the same compounds. He organized the first international scientific congress, the First International Chemical Congress, to straighten things out. The highlight of the meeting was an address by Stanislao Cannizzaro that stressed the importance of atomic weights.

A few scientists began to list the known elements in the order of their atomic weights. When they did, they found that roughly every eighth element was similar. The first to publish this information was Alexandre-Emile Beguyer de Chancourtois in 1862, but the article failed to reproduce his diagram. Without a diagram, the periodicity of the elements was far from clear. The next year John Newlands announced his version, which he called the law of octaves. People were unimpressed and claimed that just as

much periodicity could be seen if the elements were listed in alphabetical order.

Finally, in 1869 and 1870, two scientists, Dmitri Mendeléev and Julius Lothar Meyer, published clear versions of the idea. Not only was Mendeléev the first to publish, but he also announced in 1871 that the gaps in his periodic table would be filled as new elements were discovered. He specified three gaps, all of which were filled by discoveries between 1875 and 1885. As a consequence, Mendeléev gets most of the credit for the periodic table.

No one knew, however, why the properties of elements were periodic. After electrons and protons were discovered, Henry Moseley showed in 1914 that each element had a definite number of protons that normally corresponded to the same definite number of electrons. This atomic number, not the atomic weight at all, was the basis of the periodic table. With Moseley's work, it was clear that gaps existed between whole numbers of protons. These gaps have since all been filled, with the new elements falling into appropriate periodic table slots, although there has to be some restructuring from the original idea. The number of protons in an atom determines, for a neutral atom, the number of electrons, which fall into several somewhat concentric shells about the nucleus of the atom. The electrons in the outermost shell determine the chemical properties of the element. For certain elements, adding a proton to the nucleus adds an electron that is not in that outer shell, so those elements have to be grouped together on one cell of the table — the rare earths are all in the cell for atomic number 57 and the actinide series is all in the cell for atomic number 89.

Mendeléev and the others were able to define early forms of the periodic table because to a large extent the number of protons correlates with the atomic weight, especially for lighter elements. It is not until one reaches element 28, nickel, that an atomic weight is even slightly out of order. Nickel and element 27, cobalt, both have atomic weights that are close, but nickel at 58.7 is a bit less than cobalt at 58.9.



Felix Christian Klein

[b. Düsseldorf, Germany, April 25, 1849, d. Göttingen, Germany, June 22, 1925]

Klein worked with transformations while a student and gained fame by unifying the different types of geometry (Euclidean, non-Euclidean, projective, and topological) in terms of groups of transformations. Euclidean geometry, for example, can be analyzed as based in the group of reflections. Klein also invented the Klein bottle and developed the theory of the gyroscope.

structure of the atom. See also 1885 PHY.

James Clerk Maxwell explains how his statistical theory of heat works by inventing Maxwell's demon, a mythical creature that can see and handle individual molecules. By opening a gate between two vessels containing a gas only when a fast molecule is passing into one, the demon can make heat flow from cold to hot in violation of the second law of thermodynamics.

* Physics

George Johnstone Stoney [b. Oakley Park, Ireland, February 15, 1826, d. London, July 5,

1911] recognizes that the wavelengths of three lines of the four visible in the hydrogen spectrum have simple

ratios, an anticipation of Balmer's formula. This turns out to be an important step toward understanding the

I Tools

Chicago inventor Ives W. McGaffey constructs an industrial vacuum cleaner powered by a steam engine. *See also* 1865 TOOL; 1901 TOOL.

→ Transportation

Franklin Pope [b. Great Barrington, Massachusetts, December 2, 1840, d. Great Barrington, October 13, 1895] develops a centrally controlled signaling system for the Boston & Lowell Railroad. *See also* 1867 TRAN.

Otto Lilienthal [b. Auklam, Prussia, Germany, May 23, 1848, d. Rhinow, Germany, August 10, 1896] begins to study bird flight and the construction of kites with the idea of building a heavier-than-air

flying machine. *See also* 1842 TRAN; 1877 TRAN.

1872**★ Astronomy**

Henry Draper [b. Prince Edward County, Virginia, March 7, 1837, d. New York, New York, November 20, 1882] is the first astronomer to photograph the spectrum of a star, Vega. *See also* 1850 AST.

Biology

Darwin's *The Expression of the Emotions in Man and Animals* characterizes emotion in evolutionary terms and argues that emotions are the result of the inheritance of behavior from animals. *See also* 1871 ANTH; 1877 BIO.

Ferdinand Cohn begins publication of a three-volume work that is the first to treat bacteria systematically by dividing them into genera and species.

↳ Communication

Elisha Gray [b. Barnesville, Ohio, August 2, 1835, d. Newtonville, Massachusetts, January 21, 1901] forms the Western Electric Manufacturing Company, later the Western Electric Company, a pioneering communications firm. *See also* 1876 COMM.

Edison patents an electric typewriter, the prototype of the first teletype machines that will later be used by press agencies. *See also* 1855 COMM; 1902 COMM.

Christopher Sholes develops an improved form of the typewriter of 1867, which is then manufactured by Philo Remington of Ilion, New York, with the first version to go on sale in 1874. This typewriter introduces the qwerty keyboard that is now standard. *See also* 1867 COMM; 1878 COMM.

⊕ Earth science

Charles Wyville Thomson starts his tour as chief scientist on the four-year voyage of the HMS *Challenger*, the first major oceanographic expedition. *See also* 1868 BIO; 1873 MATR.

↗ Energy

George Bailey Brayton [b. Compton, Rhode Island, 1820, d. London, 1892] builds a two-stroke internal combustion engine. Exhibited in 1876 in Philadelphia, Brayton's engine will inspire Nikolaus Otto to build his own engine; however, Otto's engine will

use the four-stroke cycle devised by Beau de Rochas. *See also* 1862 ENER.

The first long-distance fuel pipeline is completed. Located in Rochester, New York, and made entirely of wood, it carries natural gas over a distance of 40 kilometers (25 miles). *See also* 1863 ENER.

Σ Mathematics

Felix Klein presents his "Erlanger Programm," a highly influential talk in which he calls for geometry to be based on groups of transformations. *See also* 1858 MATH; 1873 MATH.

Stetigkeit und irrationale Zahlen ("continuity and irrational numbers") by (Julius Wilhelm) Richard Dedekind [b. Braunschweig, Germany, October 6, 1831, d. Braunschweig, February 12, 1916] introduces the "Dedekind cut" as a definition for a real number. This identifies real numbers with the actual infinity of rational numbers that lie on one side of a cut — for example, the real number $\sqrt{2}$ exists because the infinite set of rational numbers {1, 1.4, 1.41, 1.414, 1.4142, ...}, plus all other rational numbers less than $\sqrt{2}$, exists. *See also* 1850 MATH.

German mathematician Georg Ferdinand Ludwig Philipp Cantor [b. St. Petersburg, Russia, March 3, 1845, d. Halle, Germany, January 6, 1918] establishes that a function can be represented uniquely by a trigonometric series even if the series fails to converge for an infinite set of points in an interval. This result leads Cantor to the study of actual infinite sets. *See also* 1831 MATH; 1874 MATH.



DARWIN'S INFANTS EXPRESSING SUFFERING BY WEEPING *The Expression of Emotion in Man and Animals* was one of the first books to include printed photographs. Darwin had carefully studied his own children as they grew up, although he complained that his emotional reaction to them interfered with his note taking — but the crying infants shown here were obtained from one photographer in London and from another in Hamburg. Darwin's discusses in detail how the muscles contract during weeping and the possible evolutionary reasons for these reactions.

Nouveau précis d'analyse infinitésimale ("new summary of infinitesimal analysis") by Hugues Charles Robert Méray [b. Chalon sur Saône, France, November 12, 1835, d. Dijon, France, February 2, 1911] develops a method of describing limits without using irrational numbers. *See also* 1865 MATH.

Karl Weierstrass announces to the Berlin Academy of Sciences his discovery of a function that is continuous but nowhere differentiable (that is, although its graph is an unbroken curve, the curve changes direction so often that at no point can one identify its slope). This "pathological curve" was probably discovered as early as 1861, but, typically, Weierstrass did not publish it and only used it in his lectures. *See also* 1890 MATH.

Elemente ("fundamentals") by (Heinrich) Eduard Heine [b. Berlin, March 16, 1821, d. Halle, Germany, October 21, 1881], influenced by Weierstrass's lectures, gives the modern "epsilon-delta" definition of a limit. Heine also states the powerful theorem that comes to be known as the Heine-Borel theorem (reformulated by Emile Borel in 1894): A subset of real numbers is compact if and only if it is closed and bounded. *See also* 1865 MATH; 1894 MATH.

♥ Medicine & health

Physician Jean Martin Charcot [b. Paris, November 29, 1825, d. Nièvre, France, August 1893] uses hypnosis as part of his treatment for mental illness. In 1885 Sigmund Freud is a student of Charcot's and learns this use of hypnotism from him. *See also* 1841 MED.

The first electrically powered dental drill is constructed. *See also* 1790 MED; 1957 MED.

★ Transportation

Amédée Bollée [b. LeMans, France, 1844, d. 1917] builds a steam-driven car that reaches a speed of 40 km/h (25 mph). *See also* 1835 TRAN.

The first oil tanker is built.

Paul Haenlein [b. Cologne, Germany, October 17, 1835, d. Mainz, Germany, January 27, 1905] builds the first airship to be powered by an internal combustion engine. It obtains its fuel from the gas in the balloon. *See also* 1852 TRAN; 1883 TRAN.

1873

▲ Archaeology

Heinrich Schliemann announces on June 15 that he has found Troy at a site in Turkey; his finding is confirmed by later archaeologists as to site, although they believe that he has misidentified the level at that site that was the Troy of Priam. *See also* 1870 ARCH; 1876 ARCH.

German Egyptologist Georg Moritz Ebers [b. Berlin, March 1, 1837, d. Tutzing, Germany, August 7, 1898] purchases a 20-m (65-ft) scroll that, it is claimed, had been buried with a mummy at Thebes. It turns out to be a 1600 BCE copy of a summary of Egyptian medicine that had originally been written much earlier. *See also* 1862 ARCH; 1881 ARCH.

★ Astronomy

Richard Anthony Proctor [b. London, March 23, 1837, d. New York, New York, September 12, 1888], who is more of

a science writer than a working astronomer, suggests that the craters of the Moon are formed by the impact of meteorites. At this time astronomers assume that the craters have been formed by volcanoes. *See also* 1921 AST.

❖ Biology

Italian histologist Camillo Golgi [b. Corteno (Italy), July 7, 1843, d. Pavia, Italy, January 21, 1926] discovers a new method of staining cells using silver salts that enables staining of a few neurons or neuronal systems in a tissue, making it possible to study a few out of the many thousands of systems that touch each other in the brain. *See also* 1883 BIO.

⌚ Communication

Willoughby Smith [b. Great Yarmouth, England, April 6, 1828, d. Eastbourne, England, July 17, 1891], experimenting with the use of selenium wires as electrical resistors, discovers that the resistance varies unpredictably. Eventually he observes that these variations are caused by light and that anecdotal reports of the effects of light on selenium have some basis in fact. Conductivity of selenium measurably increases on illumination, which becomes known as the photoconductive effect. His report on the sensitivity to light of selenium causes many to suggest that selenium might be used for "seeing by electricity." *See also* 1861 MATR; 1876 ENER.

Hermann Vogel [b. Doberlug, Germany, March 26, 1834, d. Berlin, December 17, 1898] improves the sensitivity of photographic collodion plates to green light by treating them with an aniline dye. Subse-

quently he improves the sensitivity of photographic plates to other colors, thus making it possible to reproduce truer colors. *See also* 1861 COMM; 1891 COMM.

☛ Energy

Hippolyte Fontaine [b. Dijon, France, April 12, 1833, d. Paris, February 17, 1917] demonstrates at the Exhibition of Vienna that the electric generator developed by Zénobe Gramme can also serve as a motor. He demonstrates that a large generator attached to a small one will turn the small one with power from the larger one. *See also* 1869 ENER.

॥ Food & agriculture

Australian wool merchant Thomas Sutcliff Mort [b. Bolton, Lancashire, England, December 23, 1816, d. Bodalla, Australia, May 9, 1878] and French engineer Eugene Dominique Nicolle [b. 1823, d. November 23, 1909] build in Australia the first refrigeration plant for meat. *See also* 1857 FOOD; 1877 FOOD.

Fred Hatch attempts to build the first modern grain silo in McHenry County, Illinois. Similar airtight storage bins for fodder had been built by both the Romans and the Chinese but were no longer in use by the 19th century. *See also* 50 CE FOOD.

Improvement of the Cereals by Patrick Shirreff [b. Mungoswells, Scotland, 1791, d. Haddington, Scotland, December 16, 1876] is published. Shirreff observes that selection of individual plants that produce more grain and using these for seed can, over the course of a quarter of a

century, produce new varieties.

❖ Materials

Charles Wyville Thomson, scientific leader of the British round-the-world expedition of the HMS *Challenger*, discovers manganese nodules lying on the ocean floor about 300 km (185 mi) southwest of the Canary Islands. *See also* 1872 EAR.

Σ Mathematics

Marius Sophus Lie [b. Nordfjordeide, Norway, December 17, 1842, d. Oslo, February 18, 1899] begins to develop the theory of continuous transformation groups. *See also* 1872 MATH; 1888 MATH.

Sur la fonction exponentielle ("on the exponential function") by Charles Hermite [b. Dieuz, France, December 24, 1822, d. Paris, January 14, 1901] shows that *e*, most familiar as the base of the natural logarithms, is not the solution to any algebraic equation, and therefore what mathematicians call a transcendental number. *See also* 1844 MATH.

♥ Medicine & health

Wilhelm Wundt publishes what many consider the most important book in the history of psychology: *Grundzüge der physiologischen Psychologie* ("principles of physiological psychology"). Wundt is the first to move psychology from the realm of philosophy and speculation into the practice of psychological experiments in the laboratory. *See also* 1858 MED; 1879 MED.

❖ Physics

James Clerk Maxwell's *Electricity and Magnetism* con-

tains the basic ideas for the laws of electromagnetism, radio waves, and pressure caused by light rays. After Maxwell's death in 1879, just before what would have been his 48th birthday, the details of his theory will be worked out and promoted by George Fitzgerald (the first to predict radio waves), Oliver Lodge (who first described how radio waves could be produced), and Oliver Heaviside (who will condense Maxwell's mathematics into the four famous partial differential vector equations known as Maxwell's equations). *See also* 1888 PHY.

Johannes Diderik Van der Waals [b. Leiden, Netherlands, November 23, 1837, d. Amsterdam, March 9, 1923] writes *Over de Continuïteit van den Gas – en Vloeistofstoestand* ("on the continuity of the gas and liquid state"), which contains an "equation of state" embracing both the gases and liquids. He demonstrates that these two states merge into each other in a continuous manner. *See also* 1869 CHEM.

I Tools

Hermann Sprengel introduces a mercury pump that is able to create a vacuum sufficient for the production of electric

filament lamps. *See also* 1871 TOOL.

Karl Paul Gottfried von Linde [b. Berndorf, Germany, June 11, 1842, d. Munich, November 16, 1934] begins work on the first movable refrigerator, using methyl ether as a coolant. *See also* 1857 FOOD; 1876 TOOL.

1874

▲ Archaeology

Famed photographer William Henry Jackson [b. Keeseeville, New York, April 4, 1843, d. New York City, June 30, 1942], working with government-sponsored surveys of the western states, is the first non-Indian to enter Mesa Verde, a collection of cliff houses in southwestern Colorado near the Four Corners region where four U.S. states meet. *See also* 1848 ARCH; 1888 ARCH.

◊ Chemistry

Jacobus Henricus van't Hoff [b. Rotterdam, Netherlands, August 30, 1852, d. Steglitz (Berlin), Germany, March 1, 1911] shows that the four bonding directions of the carbon atom point to the four vertices of a regular tetrahedron; Joseph Achille Le Bel [b. Merkwiller-Péchelbronn, Ger-

many, January 24, 1847, d. Paris, August 6, 1930] independently makes the same discovery.

↳ Communication

Alexander Graham Bell patents a multiple or harmonic telegraph that can simultaneously transmit two or more musical tones, similar to the more complex harmonic telegraph developed by Elisha Gray. It is a failed attempt to develop a telephone. *See also* 1876 COMM.

Edison develops a method for transmitting simultaneously two messages over one telegraph line or four messages in each direction over the common arrangement of a pair of telegraph wires. Thus the invention, which secures Edison's early reputation as an inventor, is called the perfected quadruplex telegraph. *See also* 1872 COMM.

Astronomer Pierre-Jules César Janssen takes a series of photographs of the transit of Venus across the Sun. The pictures are spaced 70 seconds apart by a rotating plate, and Janssen suggests that this method could be used to study the motion of animals. *See also* 1858 AST.

Alexander Graham Bell

[b. Edinburgh, Scotland, March 3, 1847, d. Nova Scotia, August 2, 1922]

Bell experimented with electrically reproducing sounds, first by using rapidly varying currents to turn electromagnets on and off. The magnets vibrated metal reeds tuned to match each current's frequency. When Bell replaced the metal reeds with a metal membrane, his device could transmit speech through wires. He named his device the telephone. Bell also invented the photophone, the first device to transmit messages by light, as well as metal detectors and new kinds of kites. In 1880 Bell helped found the magazine *Science*.



Emile Baudot [b. Haute-Marne, France, September 11, 1845, d. Sceaux, France, March 28, 1903] introduces a binary code which uses 5 bits to represent characters (for example, A is represented by the equivalent of 00011, B by 11001, etc.). This code remains in international use until 1930.

Francis Galton publishes *English Men of Science*, an investigation of the different effects nature and nurture have on achievement based on a questionnaire addressed to nearly 200 members of the Royal Society.

Computers

Martin Wiberg [b. 1826, d. 1905] of Stockholm, Sweden, builds an improved version of Babbage's Difference Engine. *See also* 1855 COMP.

Earth science

Wilhelm Philipp Schimper [b. 1808, d. 1880] identifies the Paleocene period in Earth's history. *See also* 1854 EAR.

James Geikie [b. Edinburgh, August 23, 1839, d. 1915] publishes the first edition of his *The Great Ice Age*. It contains evidence that there had been several ice ages separated by nonglacial epochs. *See also* 1856 EAR; 1894 EAR.

Ecology & the environment

Karl Wilhelm von Nägeli develops equations that describe competition among plants. These are ignored by biologists until the 1920s, when they are rediscovered by Alfred James Lotka and Vito Volterra.

Food & agriculture

Othmar Zeidler prepares

DDT, but does not discover its insecticidal properties. *See also* 1825 FOOD; 1939 FOOD.

Joseph Farwell Glidden [b. Charleston, New Hampshire, January 18, 1813, d. October 9, 1906] of De Kalb, Iowa, patents a double-stranded barbed wire with the barbs twisted in place along the wire so they cannot slip. The Glidden invention, called "the Winner," becomes the main type of barbed wire, although two other De Kalb entrepreneurs patent their own varieties of barbed wire. *See also* 1868 FOOD; 1915 TRAN.

Mathematics

Sonya Kovalevsky [b. Moscow, January 15, 1850, d. Stockholm, February 10, 1891] receives her doctorate from Göttingen University (awarded without examinations and in absentia) for outstanding work in partial differential equations, Abelian integrals, and mathematical astronomy. *See also* 1814 MATH.

Georg Cantor's *Über eine Eigenschaft des Inbegriffes aller reellen algebraischen Zahlen* ("on a property of the system of all the real algebraic numbers") is his first paper on set theory. *See also* 1883 MATH.

Medicine & health

The role of fluorides in preventing dental decay is discovered. *See also* 1967 MED.

Physics

George Stoney, in the paper "On the Physical Units of Nature," proposes that there is a definite smallest quantity of electricity, which he recognizes from the smallest amount of energy involved in a chemical bond. Stoney esti-

mates the charge to be about 10^{-20} coulomb, close to the modern value of $1.602176462 \times 10^{-19}$ coulombs. He will be the first to introduce the term *electron*, which he uses to describe this smallest amount of charge. *See also* 1897 PHY.

The Cavendish Laboratory for physics at Cambridge is completed. Although widely believed to have been named after the 18th-century physicist Henry Cavendish, it is, in fact, named after the entire Cavendish family because the 19th-century steel-making descendant of Henry, William Cavendish, financed the lab.

1875

Biology

Ernst Felix Hoppe-Seyler develops a method for classifying proteins that is still used. *See also* 1838 BIO.

Eduard Adolf Strasburger [b. Warsaw, Russia (Poland), February 1, 1844, d. Poppelsdorf, Germany, May 19, 1912] and Walther Flemming [b. Sachsenberg, Germany, April 21, 1843, d. Kiel, Germany, August 4, 1905] use dyes to study the mechanism of cellular division, which Flemming names *mitosis*, and the associated motions of the chromosomes. *See also* 1882 BIO.

Chemistry

Paule-Emile Lecoq de Boisbaudran [b. Cognac, France, April 18, 1838, d. Paris, May 28, 1912] discovers the element gallium (Ga), the first discovery of an element predicted by Dmitri Mendeléev on the basis of his periodic table. *See also* 1871 BIO.

Communication

Austrian printer Karl Klietsch develops etching on metal via a photographic method called heliogravure. The resulting plate can then be used for printing images. *See also* 1872 COMM; 1895 COMM.

George R. Carey proposes a form of "television system" in which the transmitter consists of an array of light-sensitive selenium cells that switch an array of electric lights on or off as an object moves in front of the selenium cells, thus reproducing a moving image over distance. *See also* 1861 MATR.

Alexander Graham Bell transmits the first sounds over electric cables. *See also* 1874 COMM; 1876 COMM.

On May 20 the Treaty of the Meter, establishing the International Bureau of Weights and Measures, with its headquarters at Sèvres, France, is signed in Paris. The treaty provides for a prototype meter and kilogram on which scientific and other measures are to be based. *See also* 1889 COMM; 1911 COMM.

Food & agriculture

Long after an unsuccessful attempt by Roman Emperor Claudius to drain Lago Fucino (Lacus Fucinus) in Italy, Swiss and French engineers working for Prince Alessandro Torlonia rebuild and extend the tunnel from the lake to the Liri River. This time the project, which had been started in 1852, succeeds, and the lake is converted to land. In 1951 the Italian government will settle 8000 families on the former lake. *See also* 53 CE CONS.

❖ Materials

Alfred Nobel develops blasting gelatin, a combination of nitroglycerin and nitrocellulose, which he patents in 1876. *See also* 1867 MATR; 1887 MATR.

The Sherwin-Williams Company introduces the first successful ready-made paint. Previous paints needed to be hand-mixed from several ingredients. *See also* 1948 MATR.

Σ Mathematics

British anthropologist E.R. Jones identifies tiny marks cut into bones by Neolithic cultures as tallies used to count game or otherwise used in hunting. This is the first known identification of counting among preliterate peoples.

❖ Physics

James Clerk Maxwell in "On the Dynamical Evidence of the Molecular Constitution of Bodies" writes that the laws of thermodynamics imply that atoms and molecules cannot be rigid bodies and therefore must have some internal structure.

William Crookes invents the radiometer, a device consisting of a partly evacuated glass bulb that encloses a vertical rotor with vanes that are blackened on one side while the other side is shiny. Light falling on the radiometer causes the vanes to turn, pushed by molecules of air that move faster near the warmer dark side than near the cooler shiny one.

1876

▲ Archaeology

Heinrich Schliemann at the Greek town of Mycenae excavates 19 bodies that he believes to be those of Homeric heroes such as Agamemnon and Cassandra; they are decorated with 35 pounds of gold ornaments and face masks. The five royal graves (and another that Schliemann missed) are now dated at about 1600 BCE, long before Homer. *See also* 1873 ARCH.

❖ Biology

Louis Pasteur's *Etudes sur la bière, ses maladies, causes qui les provoquent* ("studies of beer, its diseases, and the causes that provoke them"), among other things, tells of

Pasteur's discovery of anaerobic organisms, organisms that live in the absence of free oxygen (and, indeed, perish in its presence). *See also* 1865 BIO.

Explorer Nikolay Mikhaylovich Przhevalsky [b. Kimbarovo, Smolensk region, Russia, April 12, 1839; d. Karakol, Kirgiz, November 1, 1888] explores central Asia, bringing back many previously unknown species. His most famous discovery is Przhevalsky's horse, the last truly wild horse (other wild horses have domesticated ancestors).

□ Chemistry

The American Chemical Society is founded. *See also* 1792 CHEM.

The Bell telephone

Alexander Graham Bell's interest in speech therapy, which he acquired from his father and grandfather, led to the telephone. At age 15, Bell left his native Scotland and went to live in London with his grandfather. There he acquired knowledge of the mechanisms of speech and sound. After a short period of teaching in Bath, England, Bell and his parents moved to Canada. In 1871 Bell started teaching a phonetic system for the deaf devised by Bell's father, called "visible speech," to teachers of the deaf in Boston.

Bell had read a book written by Hermann Helmholtz in 1863 on the physiological theory of music in which Helmholtz described how sounds could be transmitted by electrical currents and magnets that caused metal reeds to vibrate. Bell started his own experiments, producing sounds from metal reeds by sending rapidly varying currents through electric magnets. This work resulted in the "multiple telegraph," a telegraph system that could transmit several messages simultaneously over one wire by using different frequencies. Bell patented the multiple telegraph in 1875.

In 1876 he replaced the metal reeds by a metal membrane and

found that he could reproduce any sound with it. The first transmission of a voice message happened inadvertently. His assistant, Thomas A. Watson, who was in an adjoining room, heard Bell say clearly through the telephone, "Mr. Watson, come here, I want you." A few months later Bell talked to his father over a telephone line of 13 km (8 mi). Around the end of the year, he had extended the length of this telephone line to 230 km (143 mi). Bell patented his telephone in 1876, and its commercial application spread quickly throughout the United States.

In 1880 Bell invented the photophone. He used sound to modulate a light beam and a selenium crystal as receiver. The electrical resistance of selenium varies with the intensity of light falling on it. The photophone was the first wireless way of transmitting speech, but it was limited to line-of-sight uses. Today telephone signals are also transmitted by light, not through the air, but through optical fibers.

Bell also improved Thomas Edison's phonograph by using wax cylinders instead of cylinders of metal foil. He developed devices for detecting metal fragments in the human body. One type of metal detector was tried out on U.S. President Garfield when he was shot in 1881. Bell also became interested in flight and experimented with several types of large kites.

Communication

Alexander Graham Bell patents the telephone. The microphone and receiver are identical; both consist of a magnet surrounded by a solenoid and placed close to an iron membrane. Vibrations in the membrane induce currents in the solenoid. These currents cause the membrane at the receiving end to vibrate. *See also* 1875 COMM.

On February 14, two hours after Alexander Graham Bell files for a patent on his telephone, Elisha Gray files a notice with the patent office for a workable device that would accomplish the same transmission of voice and sound (indeed, later experts think that Gray's version would have worked better than the device Bell patented). After many years of litigation, the U.S. courts declare Bell the inventor. *See also* 1872 COMM; 1888 COMM.

Edison's laboratory at Menlo Park, New Jersey, marks the start of modern industrial laboratories in the United States. *See also* 1872 COMM.

Johns Hopkins University is founded as a graduate school. It provides a new model for education in the United States and causes older schools to begin to modernize their curriculum and methods.

Computers

William Thomson (Lord Kelvin) designs a mechanical computer, the Tidal Harmonic Analyser, for solving differential equations. His ideas will be developed further by Vannevar Bush in the 1920s. Thomson shows that machines can be programmed for all sorts of mathematical

problems. *See also* 1843 COMP; 1930 COMP.

Earth science

C.W. Siemens develops a prototype gravity meter for use in measuring the depth of the ocean from its gravitational anomaly (variation from Earth's average gravitational force).

Energy

Paul Jablochkoff [b. Serdobsk, Russia, September 14, 1847, d. Russia, March 19, 1894] develops the "electric candle," an improved version of the arc light. The electric candle will burn for two hours with no mechanical adjustment because its two carbon rods are separated by porcelain clay that vaporizes as the arc burns. Alternating current is used to ensure that each rod vaporizes by the same amount while the lamp is in operation. *See also* 1845 ENER; 1878 ENER.

William Grylls Adams [b. Laneast, England, February 6, 1836, d. April 10, 1915] and his student Richard Evans Day conduct a careful experimental study of the photoelectric properties of selenium and discover that a junction between platinum and seleni-

um produces a current when exposed to light. This photoelectric effect is called the photovoltaic effect. *See also* 1873 COMM.

Materials

Sidney Thomas and his cousin Percy Gilchrist [b. Lyme Regis, England, December 27, 1851, d. December 15, 1935] develop a method for using the Bessemer process of steel making with other than low-phosphorus ores and pig iron. The Thomas-Gilchrist process involves lining the converter with a basic material such as lime and adding lime to the mixture of ores, coke, and pig iron. This process produces slag that absorbs and retains phosphorus oxides that would otherwise result in brittle, useless steel. *See also* 1856 MATR.

Mathematics

Edouard A. Lucas [b. Amiens, France, April 4, 1842, d. Paris, October 3, 1891] determines the first ironclad rule since the sieve of Eratosthenes in Hellenistic times for establishing whether or not a given natural number is a prime. *See also* 1850 MATH; 1896 MATH.

Medicine & health

Robert Koch discovers that the microorganism responsible for anthrax can be grown in culture (he uses the aqueous humor from the eyes of oxen). Koch shows that anthrax is caused by a specific bacterium and works out its life cycle. *See also* 1840 MED; 1880 BIO.

Physiologist Wilhelm (Willy) Friedrich Kühne [b. Hamburg, Germany, March 28, 1837, d. Heidelberg, June 10, 1900] discovers the enzyme trypsin in pancreatic juice and invents the term *enzyme* to distinguish those compounds that effect chemistry outside the cell. He reserves the older name *ferment* for vital processes in cells. *See also* 1871 BIO; 1897 BIO.

Neurologist Sir David Ferrier [b. Aberdeen, Scotland, January 13, 1843, d. London, March 19, 1928] publishes *The Functions of the Brain*, in which he summarizes his experiments, reported from 1873 on, using the brains of living primates and other animals to locate motor and sensory regions and to map them. The book also summarizes work by other scientists on the functions of the brain. *See also* 1870 BIO.

Robert (Heinrich Hermann) Koch

[b. Klausthal-Zellerfeld, Hanover, Germany, December 11, 1843, d. Baden-Baden, Germany, May 27, 1910]

A founder of the science of bacteriology, Koch devised a procedure in 1876 to demonstrate that the bacterium *Bacillus anthracis* causes anthrax, a disease of animals that can also be transmitted to humans. It was the first time that a particular bacterium was shown to be the cause of a particular disease. Koch also discovered the bacteria that cause tuberculosis (*Mycobacterium tuberculosis*) and cholera (*Vibrio cholerae*). He developed improved methods for staining bacteria and introduced the use of gelatin and, later, agar as growing media for bacterial colonies.



The germ theory of disease

In the middle of the 19th century, some surgeons realized that doctors could spread disease from one person to another. Ignaz Semmelweiss in 1847 reduced the number of cases of childbed fever by having surgeons wash their hands between deliveries. Joseph Lister in 1865 went further and proposed using carbolic acid (also called phenol) on patients' wounds during surgery.

Doctors were not the only agents spreading disease, of course. John Snow, a doctor in London, noticed that cholera cases were clustered where people used water from particular sources. He persuaded the authorities to remove the pump handle from a well at the center of the largest outbreak area; the number of cases in that area dropped immediately. William Budd learned of Snow's success and repeated it, stopping a cholera epidemic in Bristol in 1866 by managing the town's water supply.

Louis Pasteur urged French army surgeons to sterilize their instruments and their patients during the Franco-Prussian War of 1870. After the war, Pasteur began an extensive study of the causes of disease. He started with anthrax — a disease that affects both farm animals and humans — because another proponent of the newly developing germ theory of disease, Robert Koch, had already found the bacterium that causes anthrax in 1876. Pasteur first helped stop the spread of anthrax by proposing sterilization and burial of the bodies of animals that had died from it. Later he was to find something even more effective.

In 1879 Pasteur discovered by accident that bacteria could be weakened. In their weakened state, they failed to cause disease but still provoked immunity. He soon learned that the anthrax bacterium could be weakened in this way and by 1881 was able to demonstrate that an effective immunization against anthrax resulted from injection with the weakened bacteria. Pasteur called the process of producing immunization in this way vaccination, in recognition of Edward Jenner's use of cowpox (*vaccinia*) to prevent smallpox. Pasteur, Koch, and others developed vaccines of varying degrees of effectiveness against many of the major communicable diseases of the time — cholera, tuberculosis, tetanus, diphtheria, rabies.

Originally the germ theory applied only to bacteria, but about the same time as Pasteur was writing his major exposition of the theory, Charles Laveran discovered that the organism causing malaria is a protist (sometimes called a protozoan), not a bacterium. The agents of some diseases, especially skin diseases, may be fungi. In other communicable diseases, such as measles, neither a bacterium, protist, nor fungus could be found in the late 19th or early 20th centuries. Because of the success of the germ theory, organisms too small to be seen or trapped in filters — filterable viruses — were postulated to explain these diseases. With the invention of the electron microscope in the 20th century, such viruses were finally observed directly.

Today the germ theory of disease is so entrenched that even diseases that are not communicable — such as cancer, diabetes, and multiple sclerosis — are suspected of being caused by some "germ."

* Physics

Eugen Goldstein [b. Gleiwitz, Poland, September 5, 1850, d. Berlin, December 25, 1930] shows that the radiation in a vacuum tube produced when an electric current is forced through the tube starts at the cathode, resulting in the radiation being called cathode rays. *See also* 1855 PHY.

I Tools

Karl von Linde develops the first practical refrigerator, replacing methyl ether as a coolant with ammonia. Previously, Ferdinand Carré had used ammonia for the same purpose. *See also* 1873 TOOL; 1877 FOOD.

Werner von Siemens develops a practical selenium cell; when illuminated, its electrical resistance drops. *See also* 1873 COMM.

→ Transportation

Harry John Lawson of Brighton, England, develops the first "safety" bicycle, in which the power from the pedals is transmitted to the back wheel by a covered chain. Wheels of equal sizes are used, minimizing the danger from falls that had led some cyclists in the early 1870s to switch to the tricycle. Different sized gears connected by the chain gives the mechanical advantage. *See also* 1869 TRAN; 1885 TRAN.

1877

▲ Archaeology

Ephraim George Squier's *Peru Illustrated; Incidents of Travel and Exploration in the Land of the Incas* tells of his discovery that other South American civilizations preceded that of the Inca, notably the Chimú and Moche. *See also* 1850 ARCH; 1911 ARCH.

★ Astronomy

On August 16 and 17, Asaph Hall [b. Goshen, Connecticut, October 15, 1829, d. Goshen, November 22, 1907] discovers the two satellites of Mars, which had been foretold (accidentally) by Jonathan Swift in 1726. Hall

names them Phobos (fear) and Deimos (terror) after the two sons of Ares, the Greek equivalent of the god Mars.

Giovanni Schiaparelli thinks that he discovers "canals," or channels, on Mars. Eventually this observation fails to be confirmed, but it is considered at least as a possibility for the next 100 years.

↗ Biology

Botanist Wilhelm Pfeffer [b. Grebenstein, Germany, March 9, 1845, d. Kassel, Germany, January 31, 1920] begins his pioneering work with semi-permeable membranes, using them to measure the molecular weight of proteins.

Darwin's *The Different Form of Flowers on Plants of the Same Species* contains his concept of the evolutionary purpose of some species of plants having two different, incompatible types of flower. *See also* 1872 BIO; 1877 MED.

Chemistry

James Mason Crafts [b. Boston, Massachusetts, March 8, 1839, d. Ridgefield, Connecticut, June 20, 1917] and Charles Friedel discover that aluminum chloride is an important catalyst for reactions that bind two rings of carbon atoms together (the Friedel-Crafts reaction). *See also* 1854 CHEM.

Communication

On July 18 Edison shouts "Haloo" into the mouthpiece of a strip phonograph (a piece of waxed paper pulled through a needle attached to a diaphragm), the first recorded word. Between November 29 and December 6 a workman named John Kruesi follows a sketch made by Edison and builds the first phonograph, in which a needle attached to a diaphragm traces a groove on tinfoil placed around a rotating cylinder. The recording is replayed by the same needle and diaphragm. The first recording is of Edison reciting the children's poem "Mary Had a Little Lamb"; when it is recognizably played back in the first attempt, Edison, Kruesi, and others present are all astounded. After various minor improvements and adjustments, Edison prepares a patent application and demonstrates the device in the offices of *Scientific American* on December 7. The application is filed on December 15 and the invention announced

in the December 22 issue of the magazine. *See also* 1856 COMM.

Charles Cros, independently of Edison, proposes using the phono-autograph system invented by Scott de Martinville to reproduce sound, although he does not actually build a device. The Cros article precedes Edison's device by a few months, resulting in a French claim to the invention. *See also* 1856 COMM.

On August 15 Edison writes to T.B.A. David, president of the Central District and Printing Telegraph Company in Pittsburgh on the subject of introducing telephone service: "Friend David, I don't think we shall need a call bell as Hello! can be heard 10 to 20 feet away." (Edison apparently thought the phone line would always be open.) At that time Alexander Graham Bell envisions answering the telephone "Ahoy," so it seems likely that Edison invented the U.S. custom of saying "Hello." In Britain, people answered early telephone calls with "Are you there?" *See also* 1876 COMM.

Construction

The present Eddystone Light is started. Although it uses mainly the construction techniques developed by John Smeaton for the third Eddystone Light, its base is a solid cylinder that breaks up the waves much better than the design Smeaton and others previously had employed. The earlier lighthouses actually directed waves and spray upward toward the light itself and toward the weaker portions of the structure. *See also* 1759 CONS.

After five years of construction, the bridge over the Tay in central Scotland is completed. It consists of 85 sections of which the longest is 75 m (220 ft). On December 28, 1879, while a train is crossing the bridge, it will collapse, killing the 300 passengers on board. *See also* 1869 CONS; 1883 CONS.

Energy

Nikolaus Otto develops the four-cycle internal combustion engine, the basis of the

most common type of engine today. *See also* 1870 ENER.

Zénobe Gramme develops an electric alternator based on reversing his dynamo. It produces alternating current and does not need brushes — a source of electrical loss and mechanical wear. Only after the introduction of the transformer a few years later, however, will alternating current become important. *See also* 1832 ENER; 1884 ENER.



THE PRESENT EDDYSTONE LIGHT The dangerous Eddystone rocks off Plymouth, England, were the site of the first lighthouse to be built in the open sea. The present light completed in 1882, here seen at low tide, reveals the cylinder at the base. Above that the design is still remarkably similar to the one Smeaton used in the 18th century, although the new design by John Douglass is built on a different rock from the previous Smeaton lighthouse.

Food & agriculture

Charles Tellier [b. Amiens, France, 1828, d. Paris, 1913] starts the transport of meat cooled to 0°C (32°F) from Argentina to France aboard the ship *Paraguay*, equipped by refrigeration by Ferdinand Carré. *See also* 1857 FOOD.

Materials

F.B. Norton develops vitrified wheels for grinding metals.

Joseph Monier patents the use of reinforced concrete for the manufacture of railroad ties. *See also* 1867 MATR; 1889 MATR.

Louis-Paul Cailletet [b. Châtillon-sur-Seine, France, September 21, 1832, d. Paris, January 5, 1913] and Raoul Pierre Pictet [b. Geneva, Switzerland, April 4, 1846, d. Paris, July 27, 1929] liquefy oxygen. *See also* 1784 MATR; 1883 MATR.

Mathematics

Georg Cantor succeeds in proving that the infinite number of points on a line segment is the same as the number of points in the interior of a square. Publication is held up for a year because mathematicians reviewing the articles refuse at first to believe the result. Cantor also speculates that the infinity of real numbers, known as the continuum, is the next greater infinity than that of the natural (or counting) numbers, which comes to be known as Cantor's continuum hypothesis. *See also* 1888 MATH; 1911 MATH.

Medicine & health

Darwin's *Biographical Sketch of an Infant*, the diary of the development of his son, is the first source of child psychology. *See also* 1877 BIO.

Physician Sir Patrick Manson [b. Old Meldrum, Scotland, October 3, 1844, d. London, April 9, 1922], a specialist in tropical medicine, identifies the mosquito that carries the parasite (worm) that causes filariasis, a.k.a. elephantiasis from one of the symptoms. *See also* 1881 MED.

Louis Pasteur notes that some bacteria die when cultured with certain other bacteria, indicating that one bacterium gives off substances that kill the other. Some 60 years pass before this observation is put to use, when René Jules Dubos discovers the first antibiotics produced by a bacterium. *See also* 1939 MED.

J. Friedrich A. von Esmarch introduces the antiseptic bandage. *See also* 1869 MED.

Transportation

Enrico Forlanini [b. Milan, Italy, December 11, 1848, d. Milan, October 9, 1930] builds a helicopter with two counter-rotating propellers driven by a steam engine. He achieves a height of 15 m (45 ft) for a flight of one minute's duration. *See also* 1853 TRAN; 1907 TRAN.

About this time German aeronautical engineer Otto Lilienthal begins to build and test a series of gliders that he launches from the top of a hill and steers by moving his legs. He develops the first glider to use arched wings similar to those of a bird. *See also* 1871 TRAN.

John Thornycroft [b. Rome, February 1, 1843, d. Isle of Wight, June 28, 1928] patents an air-cushion vehicle but does not succeed in building a working prototype. *See also* 1955 TRAN.

1878

Biology

Robert Warrington of England shows that microorganisms convert ammonium compounds in fertilizers into nitrites and nitrates, which can be absorbed by plants. *See also* 1850 BIO.

Communication

William Crookes, in an address to the Royal Society on November 30, describes his experiments in passing electric discharges through an evacuated glass tube, an early form of the cathode-ray tube. His work not only sets the stage for television pictures produced by cathode-ray tubes but also lead directly to the discovery of X-rays and gas-discharge lamps. *See also* 1895 PHY.

On January 28 the first commercial telephone exchange opens in New Haven, Connecticut. *See also* 1876 COMM.

Frederick E. Ives [b. Litchfield, Connecticut, February 17, 1856, d. Philadelphia, Pennsylvania, May 27, 1937], while still a college student, invents the first halftone process for printing photographs.

The Remington No. 2 typewriter introduces the shift bar, a great improvement on the typewriter invented by Christopher Sholes in 1867. One of the first users is Mark Twain, who is the first to deliver a typewritten manuscript to a publisher. *See also* 1872 COMM; 1892 COMM.

Musician David Edward Hughes [b. London, May 16, 1831, d. London, January 22, 1900] discovers that the pressure of sound waves can be

used to change electrical resistance in carbon lying loosely between electrical terminals. Hughes uses this effect to create the first microphone.

Andriano de Paiva describes the concept of television and experiments in transmitting images in *La télescopie électrique basée sur l'emploi de sélénium* ("electric telescopy based on using selenium"). The images are all transmitted by wire, based on the ideas of the telephone and telegraph, rather than being broadcast.

Earth science

Swedish geologist Nils Adolf Nordenskiöld [b. Helsinki, Finland, November 18, 1832, d. Dalbyö, Sweden, August 12, 1901] starts on a voyage in which he will become the first person to pass through the Northeast Passage and circumnavigate Asia.

Energy

Hiram Stevens Maxim [b. Sangerville, Maine, February 5, 1840, knighted 1901, d. Streatham, England, November 24, 1916] invents a graphite-rod incandescent lamp that, although commercially installed in 1880 by the United States Electric Lighting Company, eventually loses in commercial competition to Edison's lamp. *See also* 1879 ENER.

Charles Francis Brush [b. Euclid, Ohio, March 17, 1849, d. Cleveland, Ohio, June 15, 1929] in September develops an improved carbon-arc lamp, which he demonstrates in a Cleveland department store. He builds and patents an electric generator to go with the arc lamp. *See also* 1876 ENER.

Karl Benz [b. Karlsruhe, Ger-

many, November 25, 1844, d. Ladenberg, Germany, April 4, 1929] designs a two-stroke internal combustion engine. *See also* 1885 TRAN.

James Wimshurst [b. Poplar, England, April 13, 1832, d. Clapham, England, January 3, 1903] develops a very efficient electrostatic generator that uses two counter-rotating plates. *See also* 1775 ENER.

Food & agriculture

In America Anna Baldwin invents the suction milking machine. The first successful application of the device is made in 1913 by Carl Gustav de Laval. *See also* 1913 FOOD.

Mathematics

James Joseph Sylvester founds the *American Journal of Mathematics*, the first U.S. research journal in mathematics.

Medicine & health

Physiologist Paul Bert [b. Auxerre, France, October 17, 1833, d. Hanoi, Indochina (Vietnam), November 11, 1886] announces that dissolved nitrogen in the blood of people working under pressurized air causes the disease commonly known as the “bends” or caisson disease. He proposes that if air pressure is lowered by stages the disease will be prevented, which is correct. *See also* 1779 CONS.

Tools

Samuel Pierpont Langley [b. Roxbury, Massachusetts, August 22, 1834, d. Aiken, South Carolina, February 22, 1906] builds a radiometer consisting of two metallic grids connected to a Wheatstone bridge. When one grid is exposed to the radiation to be measured, the increase in tem-

perature changes its resistance, which is then measured by the bridge. *See also* 1850 TOOL.

1879

► Anthropology

Maria Santuola, while exploring Altamira Cave with her father Marcelino, is the first person known to have discovered Cro-Magnon cave paintings. Smaller than her father, she can stand upright in places where he must crawl. As a result, she becomes the first person in 10,000 years to see the bisons painted on the cave's ceiling. *See also* 1940 ANTH.

► Archaeology

Archibald Sayce [b. 1845, d. 1933] recognizes the Hittite civilization of ancient Turkey. He will publish *The Monuments of the Hittites* in 1881.

★ Astronomy

George Howard Darwin [b. Down House, Kent, England, July 9, 1845, d. Cambridge, England, December 7, 1912] proposes that the Moon was formed from material thrown from Earth's crust when Earth was rotating very fast. Subsequently, tidal friction slowed Earth's rotation and caused the Moon to move farther away. This theory seems plausible until the 1960s.

► Biology

Biochemist (Ludwig Karl Martin Leonhard) Albrecht Kossel [b. Rostock, Germany, September 16, 1853, d. Heidelberg, Germany, July 5, 1927] begins his studies of nuclein, a substance found in cells, which leads to his discovery of nucleic acids (DNA

and RNA). *See also* 1869 BIO; 1910 BIO.

▷ Chemistry

Lars Fredrik Nilson [b. Östergötland, Sweden, May 27, 1840, d. Stockholm, May 14, 1899] discovers the element scandium (Sc), which he names after Scandinavia. Per Teodor Cleve [b. Stockholm, February 10, 1840, d. Uppsala, Sweden, June 18, 1905] shows that scandium is one of the elements predicted by Dmitri Mendeléev on the basis of his periodic table.

Paul-Emile Lecoq de Boisbaudran discovers the element samarium (Sm).

Per Teodor Cleve discovers the elements thulium (Tm) and holmium (Ho).

Russian chemist Vladimir Markovnikov [b. Knyaginino, Russia, December 25, 1837, d. Moscow, Feb 11, 1904] shows that carbon rings with four atoms can be formed; before this feat, it was believed that all carbon-based molecules could have rings of six atoms only.

▷ Communication

During a measles epidemic in Lowell, Massachusetts, physician Moses Greeley Parker becomes concerned that one or more of the four telephone switchboard operators will become ill and that the telephone system, which depends on the operators' knowing each of the 200 or so subscribers' names, will break down. He proposes that numbers be given to each of the subscribers, which results in the first telephone numbers being assigned. The system of using numbers soon spreads to other exchanges.

George Eastman [b. Waterville, New York, July 12, 1854, d. Rochester, New York, March 14, 1932] patents a photographic emulsion coating machine, allowing him to start mass producing photographic dry plates. *See also* 1871 COMM.

■ Construction

The first skyscraper, the Leiter Building, is completed in Chicago, Illinois. A wave of Chicago skyscraper building soon follows. *See also* 1883 CONS.

● Earth science

Geologist Charles Lapworth [b. Faringdon, England, September 20, 1842, d. March 13, 1920] settles a dispute between followers of Roderick Impey Murchison and those of Adam Sedgwick by putting Murchison's lower Silurian and Sedgwick's upper Cambrian into a new period called the Ordovician. *See also* 1838 EAR.

▼ Energy

In America Edison and in England Joseph Swan each produce carbon-thread electric lamps that can burn for practical lengths of time. Edison's lamp uses a carbon fiber derived from cotton and burns on October 21 for at least 13½ hours, although there is some evidence that one of Edison's first lamps of this design burns for about 40 hours. Later in the year, 115 of the Edison lamps are installed in the paddle steamer *Columbia*. *See also* 1880 ENER.

Charles Brush installs in a public square in Cleveland a dozen of the carbon-arc lamps he has developed. *See also* 1878 ENER.

Lights and lighting

The production of light is probably the second oldest technology of humankind, coming about a million years after the development of stone tools. Prehistoric peoples used fire for heating and cooking, but also for the production of light. The simplest lighting device was the torch.

Lighting devices became more practical with the introduction of the oil lamp. In its simplest form, the oil lamp consists of a small receptacle with a groove or nozzle in which a wick burns. Lamps of this design have been found in caves dating from the end of the Old Stone Age.

The Romans developed a form of lamp that has no container — the candle. Candles, made from tallow, beeswax, and bayberry wax, continued to be a major source of illumination through the 18th century.

Oil lamps became more sophisticated, but the basic principle of a wick and an inflammable liquid continued in use for thousands of years. Whale oil was used during the 19th century until methods were found to produce the light oil kerosene from petroleum. Kerosene lamps were the main source of light in rural parts of the United States until rural electrification in the 1930s and 1940s. The better kerosene lamps used a mantle instead of a wick; the mantle is a treated net that absorbs gas and glows with a bright, white light when lit. Campers today often use lamps that combine a volatile fuel with a mantle.

At the end of the 18th century gas light was introduced in cities. Natural gas, or more commonly gas made from wood or coal, was piped to street lamps and into houses. As a result, much of the 19th century is known as the Gaslight Era.

In 1808 Humphry Davy developed the arc light, which eventually was put to several uses. Although the electric arc between

two carbon electrodes produced a brilliant light, it generated large amounts of smoke and heat. Furthermore, the carbon was gradually consumed, so the distance between the electrodes needed to be shortened frequently to maintain the proper amount of gap. Despite these problems, arc lamps during the 19th century were used in public places in Paris and London and especially in lighthouses. However, they did not become the basis of household lighting.

The greatest breakthrough in lighting came in 1879 with the invention of the filament lamp, or incandescent bulb, by Edison in the United States and Joseph Swan in England. It had been known since 1838 that an electric current through a thin filament of carbon in a vacuum produces light. The achievement of Edison and Swan was to develop this method into a practical incandescent lamp that could burn for 40 or more hours. The Gaslight Era did not last long after the electric lamp was invented, for it quickly displaced gas.

The fluorescent lamp was developed in the 1930s. It consists of a tube that is coated on the inside with a fluorescent material and filled with mercury vapor. An electric discharge in the vapor produces ultraviolet light, which in turn causes the coating to fluoresce. By adjusting the coating, fluorescent lamps can be produced to give light with wavelengths that are closer to natural sunlight than can be achieved with the incandescent bulb. The lamps also operate on less electric power. Despite these advantages, fluorescent lamps have failed to replace incandescent bulbs in most homes, partly because the initial expense is greater for a bulb and partly because the lights most available seem to many to produce a harsh light.

The light of the future is expected to be electronic rather than electric. Arrays of light-emitting diodes are used for many purposes already that were once the province of incandescent bulbs.

William Sugg invents the Sugg-Argand lamp, which uses coal gas for fuel in an Argand-type lamp and produces an economical light of high intensity. *See also* 1784 ENER; 1887 ENER.

English-American inventor Elihu Thomson [b. Manchester, England, March 29, 1853, d. Swampscott, Massachusetts, March 13, 1937] demonstrates the use of induction coils to step down voltage while increasing current, the basic principle of the electric transformer. Thomson operates the coils in a parallel circuit, which

is the secret of the commercially successful transformer developed six years later. *See also* 1831 ENER; 1883 ENER.

II Food & agriculture
Carl Gustav Patrik de Laval [b. Orsa, Sweden, May 9, 1845, d. Stockholm, February 2, 1913] patents a centrifugal separator for making butter from milk. *See also* 1890 FOOD.

Ira Remsen [b. New York City, February 10, 1846, d. Carmel, California, March 5, 1927] and Constatin Fahlberg [b. Tambow, Russia, December 22, 1850, d. August 15, 1910]

discovers the artificial sweetener saccharin while studying coal tar. *See also* 1965 FOOD.

❖ Materials

The Wakefield Rattan Company in the United States develops a method of making wicker furniture from the fibrous pit of the rattan stalk (a plant native to Indonesia and the Philippines long used in its natural state for making rattan furniture or split to make cane furniture). Unlike traditional rattan furniture, the new form, which Wakefield calls reed furniture, can be

stained, painted, and, when wet, bent into scrollwork. *See also* 1920 TOOL.

William Siemens invents an electric furnace of the arc type, which, with modifications and improvements, is the arc furnace used today.

German organic chemist Otto Wallach [b. Königsberg (Kaliningrad, Lithuania), March 27, 1847, d. Göttingen, Germany, February 26, 1931] starts studying essential oils, such as menthol and camphor. *See also* 2000 BCE MATR; 1884 MATR.

Σ Mathematics

Begriffsschrift (“conceptual notation”) by Gottlob Frege [b. Wismar, Germany, November 8, 1848, d. Bad Kleinen, Mecklenburg, Germany, July 26, 1925] is the first serious attempt to reduce all of mathematics to statements in formal logic. *See also* 1830 MATH; 1884 MATH.

Richard Dedekind is the first to expressly define a field in mathematics: A field is a set that obeys certain simple rules for addition and multiplication, such as the distributive rule that $a \times (b + c) = ab + ac$. Examples include the rational, real, and complex number systems.

♥ Medicine & health

Louis Pasteur discovers by accident that weakened chicken cholera bacteria fail to cause disease in chickens and that chickens previously infected with the weakened bacteria are immune to the normal form of the bacteria, thus paving the way for the development of vaccines against many diseases, not just smallpox. *See also* 1796 MED; 1881 MED.

Bacteriologist Charles Chamberland [b. Chilly-le-Vignoble, France, March 12, 1851, d. Paris, May 2, 1908], working with Pasteur, develops the first version of the autoclave for sterilizing medical equipment.

Wilhelm Wundt founds the first laboratory for psychology in Leipzig, Germany. *See also* 1873 MED; 1888 MED.

German physician Albert Neisser [b. Schweidnitz, Germany, January 22, 1855, d. Breslau (Wrocław, Poland), July 30, 1916] discovers the

bacterium that causes gonorrhea.

❀ Physics

Edwin H. Hall [b. North Gorham, Maine, November 7, 1855, d. Cambridge, Massachusetts, November 20, 1938] discovers the effect named for him: An electric current in a conductor that is perpendicular to a magnetic field causes electric charges to build up on one side of the conductor.

Josef Stefan [b. St. Peter, Carinthia, Austria, March 24, 1835, d. Vienna, January 7, 1893] discovers that the total radiation of a body is proportional to the fourth power of its absolute temperature, now known either as Stefan’s fourth-power law or as the Stefan-Boltzmann law. Ludwig Boltzmann will prove the law from first principles in 1884. *See also* 1884 PHY.

I Tools

Dayton, Ohio, saloon keeper James Ritty [b. 1837, d. 1918], having seen how ships’ logs function, uses similar principles to develop and patent the first cash register, which he called Ritty’s Incorruptible Cashier. It is not a commercial success. *See also* 1884 TOOL.

↗ Transportation

Werner von Siemens demonstrates an electric railway 500-m (1640-ft) long at a Berlin exhibition. Two years later he builds the world’s first public service electric street railway at Lichterfelde, a suburb of Berlin. *See also* 1880 TRAN.

1880

▲ Archaeology

Désiré Charnay [b. Fleure-sur-

l’Arbesle, France, May 2, 1828, d. Paris, October 24, 1915] finds wheeled toys at Tenenepanco, high on Mount Popocatepetl in Mexico, the first evidence of wheels of any kind in the pre-Columbian New World.

❖ Biology

Robert Koch starts using solid cultures for growing microbes (gelatin or agar). *See also* 1876 MED.

Francis Maitland Balfour [b. Edinburgh, Scotland, November 10, 1851, d. Mont Blanc, Switzerland, July 19, 1882] suggests that animals with backbones or with notochords (long rods of stiffened tissue that supports the body) be classified as the phylum Chordata, a suggestion that will be accepted by taxonomists. Animals with true backbones are classified as Vertebrata, a sub-phylum of Chordata.

Francis Galton in an article in *Nature* reports the existence of the phenomenon of synesthesia, a condition in which a person perceives different sensory experiences from those of a person without the condition — musical tones may be accompanied by colors, numerals for different numbers or different letters of the alphabet may each be perceived with different colors, although printed in black, or touch sensations may result in the perception of tastes.

⌚ Communication

Alexander Graham Bell patents the photophone. A phone circuit sets a mirror in vibration and reflected Sun rays are detected by a selenium detector, thus allowing the transmission of sound by light. *See also* 1965 COMM.

The New York *Daily Graphic* of March 4 contains the first use of a screened photograph. Photographs are screened because printing on continuous tones smears ink, distorting the image. In a screened photograph a pattern of tiny dots indicates shading by the density of the dots (that is, the number per square unit of equal-sized dots). Individual dots receive too little ink to smear — it is absorbed by the paper. *See also* 1878 COMM; 1885 COMM.

Scottish missionary Henry Faulds [b. 1843, d. 1930] writes to *Nature* from his university post in Japan to propose that since fingerprints are never identical, they can be used to identify people positively and perhaps aid in criminal investigations. This letter sparks Sir William James Herschel to report on his similar use of fingerprints in India, and propels the British government into setting up a system of fingerprint identification. *See also* 1860 COMM; 1901 COMM.

⊕ Earth science

John Milne, English geologist [b. December 30, 1850, d. Shide, Isle of Wight, July 30, 1913] invents the modern seismograph for measuring earthquake waves. *See also* 1855 EAR; 1888 EAR.

↗ Energy

Pierre and Jacques Curie discover the piezoelectric effect, which is that certain substances produce an electric current as a result of pressure on them; also, an electric current can change the dimensions of these substances slightly. The effect will have many applications, such as in

electronic watches, where a vibrating crystal stabilizes an electronic oscillator, in microphones and pick-up elements of record players, and in the scanning tunneling microscope.

Edison discovers that bamboo produces a carbon fiber of superior quality, lighting his newly developed incandescent lamps for as long as 1200 hours. *See also* 1879 ENER; 1904 ENER.

Edison's first electric generation station, designed mainly for lighting, is opened in London.

II Food & agriculture

The first refrigerated meat from Australia arrives in London aboard ships. *See also* 1877 FOOD; 1881 FOOD.

❖ Materials

Para red, the first azo dye, is discovered; although it dyes cellulose fabrics a brilliant red, it is not very fast. A series of improvements on para red over the next 75 years form the azo family of increasingly fast and colorful dyes.

Σ Mathematics

John Venn, in a paper called "On the Diagrammatic and Mechanical Representation of Propositions and Reasonings," introduces his famous diagrams, now known as Venn diagrams. These intersecting circles can be used to indicate the union or intersection of sets or to show logical consequences. *See also* 1866 MATH; 1881 MATH.

A. Amthor makes the first serious progress in solving Archimedes' problem of the "cattle of the Sun," which Archimedes is thought to have first proposed to Eratosthenes



Pierre Curie

[b. Paris, May 15, 1859, d. Paris, April 19, 1906]

In 1880 Curie and his brother Jacques [b. Paris, October 29, 1856, d. 1941] observed that certain crystals respond to pressure by separating electric charge on opposing faces. The Curies named the phenomenon piezoelectricity ("pressure electricity"). Pierre Curie then investigated magnetism; he was the first to determine that at a certain temperature, specific to each substance, the magnetic properties of the substance change (the Curie point). When his wife, Marie Skłodowska Curie, studied radioactivity, Pierre Curie joined her research effort and became a codiscoverer of polonium and radium.

around 300 BCE. *See also* 1773 MATH; 1965 MATH.

♥ Medicine & health

Physician Josef Breuer [b. Vienna, Austria, January 15, 1842, d. Vienna, June 20, 1925] treats a patient suffering from psychological disabilities by having her relate her fantasies, sometimes using hypnosis; this relieves her difficulties. Breuer tells Sigmund Freud of his experience, and Freud soon begins similar treatments for his patients. *See also* 1872 MED; 1885 MED.

Louis Pasteur's "On the Extension of the Germ Theory to the Etiology of Certain Common Diseases" develops the germ theory of disease. This year he also demonstrates his findings on vaccination to the Academy of Medicine. *See also* 1882 MED.

Charles-Louis-Alphonse Laveran [b. Paris, June 18, 1845, d. Paris, May 18, 1922] discovers a parasite in the blood of a soldier suffering from malaria. It is the first known recognition that a protist can cause a human disease. *See also* 1866 BIO; 1885 BIO.

✿ Physics

Johannes Van der Waals for-

mulates his Law of Corresponding States, based on the concept of the critical points for a gas, below which a substance can exist as both a gas and a liquid. The law is a general form of the equation of state, applicable to all substances, obtained when pressure, volume, and temperature are expressed as simple functions of the critical points. *See also* 1869 CHEM; 1910 PHY.

I Tools

Jacques-Arsène d'Arsonval [b. La Borie, France, June 8, 1851, d. La Borie, December 31, 1940] invents an improved form of the galvanometer, now known as the d'Arsonval galvanometer. *See also* 1820 TOOL; 1884 TOOL.

Swiss army officer Eduard Alexander Rubin [b. 1846, d. 1920] invents the jacketed bullet about this time, a lead core for weight encased in a hardened metal "jacket" to protect the core from being blown apart by large charges or being deformed by air resistance or in the process of striking a target. *See also* 1846 TOOL; 1884 TOOL.

↗ Transportation

Edison demonstrates an elec-

tric tramway in Menlo Park, New Jersey (Edison, New Jersey). *See also* 1879 TRAN; 1888 TRAN.

About this time Otto Lilienthal builds a pair of connected gliders, one flying above the other, in hopes of getting more lifting power. *See also* 1877 TRAN.

After chairing an international conference on the idea in 1879, Ferdinand de Lesseps begins construction of the sea-level Panama Canal through Central America (locks are incorporated into the design in 1887). *See also* 1869 TRAN; 1889 TRAN.

1881

▲ Archaeology

Emile Charles Albert Brugsch [b. Berlin, February 24, 1842, d. Nice, France, January 14, 1930] becomes the first archaeologist to enter the place where 36 members of the Egyptian royal family, including many of the most famous, had been reburied. The site, near Luxor, had been located about ten years earlier by Arabs, who removed small pieces from it and sold them. *See also* 1873 ARCH.

★ Astronomy

Edward Emerson Barnard [b. Nashville, Tennessee, December 16, 1857, d. Chicago, February 6, 1923] makes his first discovery of a comet. At the time philanthropist H. H. Warner was giving each American who discovered a comet \$200, and Barnard went on to earn enough this way within a few years to make the down payment on a house. In his lifetime, Barnard discovers 16 comets. *See also* 1892 AST.

Samuel Langley invents the bolometer, an ultra-sensitive device for measuring temperature, which he uses to measure the radiation from the Sun in both the visible and infrared regions. *See also* 1856 TOOL; 1887 AST.

Ⓑ Biology

Paul Ehrlich [b. Strehlen, Germany, March 14, 1854, d. Bad Homburg, Germany, August 20, 1915] introduces staining of bacteria with methylene blue. *See also* 1873 BIO; 1884 BIO.

Ⓒ Communication

Etienne-Jules Marey develops a camera that will take many pictures of the same scene in a short period of time. It is a predecessor of the motion picture camera. Marey uses it to learn about animal locomotion. *See also* 1888 COMM.

Frederick E. Ives prints the first three-color halftone photographic reproduction. *See also* 1878 COMM; 1885 COMM.

Ⓓ Energy

Fernand Forest [b. Clermont-Ferrand, France, 1851, d. Monaco, 1914] introduces an internal combustion engine in

which the cylinder is cooled by air. Air-cooled cylinders have since been used in motorcycle, car, and airplane engines, although water-cooled motors are more common for automobile engines.

U.S. President James A. Garfield, shot by an assassin on July 2, is given air conditioning from a device that sucks in outside air, then passes the air over salted ice and into the sick room. It lowers the temperature by 10°C (20°F) for a period of 58 days, using over 250 tons of ice; Garfield dies anyway. *See also* 1880 FOOD; 1902 TOOL.

French engineer Camille Faure [b. 1840, d. 1898] improves the Planté lead-acid storage battery, making it essentially like the ones used to start automobiles today. *See also* 1859 ENER; 1900 ENER.

Ⓔ Food & agriculture

Refrigerated railway cars are used in the United States for transporting meat from the slaughterhouses in Chicago and Kansas City. *See also* 1880 FOOD; 1913 FOOD.

Ⓕ Materials

Henry Simon in Manchester, England, and separately Albert Hussner in Gelsenkirchen, Germany, develop a system for making high-quality coke while recovering the coal gas, oil, and tar during the process; improvements on this method continue to be used today. *See also* 1858 MATR.

Ⓖ Mathematics

Elements of Vector Analysis by Josiah Gibbs develops a system of vectors in three dimensions. It is primarily a pamphlet Gibbs prints for the use

of his students at Yale. *See also* 1843 MATH.

Leopold Kronecker [b. Liegnitz, Silesia (Poland), December 7, 1823, d. Berlin, December 29, 1891] gives various examples of systems other than the rational and real number systems that also form mathematical fields. *See also* 1879 MATH.

John Venn publishes *Symbolic Logic*. *See also* 1880 MATH.



(Josiah) Willard Gibbs

[b. New Haven, Connecticut, February 11, 1839, d. New Haven, April 28, 1903]

Although Gibbs was the founder of chemical thermodynamics, his highly theoretical work seems to belong more to the world of mathematical physics, of which he was a professor (at Yale), than to chemistry. He developed mathematical techniques for predicting the outcome of chemical reactions before making a physical trial. He also derived the laws of thermodynamics from the basic concept of heat as movement of particles.

Ⓗ Medicine & health

Louis Pasteur develops the first artificially produced vaccine, against anthrax, a deadly disease that affects both animals and humans. On May 5 he successfully demonstrates that vaccination of sheep and cattle against anthrax prevents their falling ill with the disease after injection with live bacteria; unvaccinated animals die when given the same amount

of live bacteria. *See also* 1879 MED; 1885 MED.

When U.S. President Garfield is shot by an assassin, Alexander Graham Bell invents a metal detector for locating bullets in the human body. The principle of the telephone is used to magnify sounds produced by electromagnetic interference by metal (in effect, the first microphone). Although tests of various kinds suggest that Bell's detectors can find buried bullets, they fail on Garfield, who eventually dies from infection of the wound. Later theories to account for the failure of Bell's device in this instance revolve around interference from metal bed-springs or around the bullet simply being too deeply embedded for the device to detect.

Carlos Finlay [b. Cuba, December 3, 1833, d. Havana, August 20, 1915] suggests that the mosquito is the carrier of yellow fever. *See also* 1877 MED.

Karl J. Erberth identifies the bacillus that causes typhoid fever (now known to be a form of *Salmonella*). *See also* 1883 MED.

Ⓘ Physics

J.J. Thomson introduces the concept of electromagnetic mass. He deduces from Maxwell's equations that the mass of an object changes when electrically charged.

Hermann von Helmholtz shows that the electrical charges in atoms are divided into definite integral portions, rediscovering the idea that there is a smallest unit of electricity. *See also* 1874 PHY.

The paper “On the Relative Motion of the Earth and the Luminiferous Ether” by Albert Abraham Michelson [b. Strelno, Prussia (Strzelno, Poland), December 19, 1852, d. Pasadena, California, May 9, 1931] suggests that the ether, postulated to explain the transmission of light, may not exist since Michelson cannot detect it in a sensitive experiment. *See also* 1881 TOOL; 1887 PHY.



J. J. (Joseph John) Thomson

[b. Chetham Hill, England, December 18, 1856, d. Cambridge, Massachusetts, August 30, 1940]

In 1897 Thomson proved that a cathode ray consists of equal-mass particles that respond to both electric and magnetic fields. The particle mass is that of the smallest mass change during ionization, much smaller than a hydrogen atom. The tiny charged particle Thomson had identified was the electron. Thomson also made the first version of a mass spectrometer (a device that separates ions by mass) and used it to find two isotopes of neon, physical proof that isotopes, then only suspected in radioactive decay, exist.

I Tools

Albert Michelson invents the interferometer, a device for measuring distances by observing interference patterns of a light beam that has been split in two. *See also* 1881 PHY; 1887 PHY.

William Edward Ayrton [b. London, September 14, 1847, d. London, November 8, 1908] and John Perry invent a device using a band or rope around a pulley for measuring force (a dynamometer) and put forward the first electro-mechanical principles for using measurement of electrical resistance to obtain values for force measurements. As a part of their work they also develop a brake system for railroad safety.

Transportation

The first electric streetcar is introduced in Berlin. *See also* 1879 TRAN.

Hermann Ganswindt [b. East Prussia, June 12, 1856, d. Berlin, October 25, 1934] calculates the velocity a vehicle has to reach for escaping Earth's gravitational force. This is known as the escape velocity and it varies for different heavenly bodies; for Earth its value is 11.3 km (7.2 mi) per second. *See also* 1891 TRAN.

1882

★ Astronomy

Edward Charles Pickering [b. Boston, Massachusetts, July 19, 1846, d. Cambridge, Massachusetts, February 3, 1919] develops the method of photographing the spectra of several stars at a time by placing a large prism in front of the photographic plate. *See also* 1872 AST.

David Gill [b. Aberdeen, Scotland, June 12, 1843, d. London, January 24, 1914] makes a classic photograph of the Great Comet of 1882 that shows so many stars that the idea of stellar cataloging by photography is born. Gill proceeds to map most of the stars visible in the Southern Hemisphere using his new method. *See also* 1750 AST; 1885 AST.

↗ Biology

Eduard Strasburger coins the terms *cytoplasm* for the part of a cell within the membrane but outside the nucleus and *nucleoplasm* for the material within the nucleus. *See also* 1875 BIO.

Friedrich August Löffler [b. Frankfort an der Oder, Germany, June 24, 1852, d. Berlin, April 9, 1915] discovers the bacterium causing glanders,

Burkholderia mallei, a disease that primarily affects horses but can be contracted by other animals and (rarely) humans.

Wilhelm Engelmann [b. Germany, 1843, d. 1909] shows that red light is the most effective in providing plants with energy (photosynthesis).

▷ Chemistry

Viktor Meyer discovers thiophene, a pentagonal ring with sulfur replacing two of the carbon atoms in a benzene ring, when a common test for benzene fails to work on a pure sample of benzene. Careful work shows that all previous samples of benzene known had been contaminated with thiophene, which is what the test actually detects. *See also* 1865 CHEM; 1889 CHEM.

⌚ Communication

German physicist Ernst Abbe [b. Eisenbach, Germany, January 23, 1840, d. Jena, Germany, January 14, 1905] founds the Zeiss Laboratory for Optical Technology in Jena, Germany. *See also* 1887 COMM.

Lars Magnus Ericsson [b. Värmskog, Sweden, 1846, d. December 1926] introduces the telephone nicknamed the “dachshund,” the first tele-

phone for which the handset combines the microphone and earpiece and rests on a cradle. *See also* 1880 COMM; 1884 COMM.

■ Construction

The largest apartment complex to date is built in New York City, the first to be larger than Pueblo Bonito built by the Anasazi of western North America around 1100. *See also* 1100 CONS.

⊕ Earth science

Balfour Stewart [b. Edinburgh, Scotland, November 1, 1828, d. near Drogheda, Ireland, December 19, 1887] suggests the existence of the ionosphere to account for small daily changes in Earth's magnetic field. *See also* 1902 EAR.

↗ Energy

Physicist Marcel Deprez [b. Chatillon-sur-Loing, France, December 12, 1843, d. Vincennes, France, October 13, 1918] shows that electric energy can be transported over longer distances by increasing its voltage. In an experimental setup between Munich and Nielsbach, a distance of 57 km (35 mi), 38 percent of the electric energy reaches its destination, using a

potential difference of 1343 volts. In subsequent experiments Deprez increases the voltage, thus initiating high-voltage transport of electrical energy over long distances. Deprez fails to patent his discovery. *See also* 1891 ENER.

The first hydroelectric power plant goes into operation in Appleton, Wisconsin, on September 30. A 107-cm (42-in.) water wheel powers two direct-current generators that together provide about 25 kW of power. *See also* 1869 ENER.

The Pearl Street power station in New York City, built by Edison, brings electric lighting to the United States on September 4. It consists of three 125-horsepower steam generators that supply enough current for 5000 lamps in 225 houses. Edison earlier in the year opens a similar station in London. *See also* 1885 ENER.

French engineer Abel Pifre and mathematician Augustin Mouchot demonstrate in Paris the use of solar energy for power. Solar radiation, captured by a 2.2-m (7-ft) parabolic mirror, heats water in a small boiler placed at its center, thus producing steam to drive a steam engine. This in turn powers a printing press that prints 500 copies per hour of Pifre's newspaper, named *Soleil-Journal* (Sun newspaper). *See also* 1891 ENER.

❖ Materials

Joseph Swan produces artificial silk (rayon) from cellulose acetate. *See also* 1857 MATR; 1884 MATR.

Σ Mathematics

Über die Zahl pi ("on the number π ") by Carl Louis Ferdinand von Lindemann [b.

Hanover, Germany, April 12, 1852, d. Munich, March 6, 1939] proves that π is a transcendental number, implying that the circle cannot be squared with straightedge and compass. *See also* 1768 MATH.

Vorlesungen Über Neuere Geometrie ("proposal for modern geometry") by Moritz Pasch [b. Breslau (Wrocław, Poland), November 8, 1843, d. Bad Homburg, Germany, September 20, 1930] is the first modern attempt to reform Euclid's geometry by changing the undefined terms and postulates to produce a more secure logical foundation. *See also* 1889 MATH.

Felix Klein invents the surface in four-dimensional space that has one side, no edge, and no inside or outside, now called the Klein bottle. *See also* 1865 MATH; 1895 MATH.

♥ Medicine & health

Robert Koch discovers the bacterium that causes tuberculosis, the first definite association of a germ with a specific human disease. *See also* 1880 MED; 1890 MED.

Paul Ehrlich introduces his diazo test for diagnosing typhoid fever from a chemical reaction with urine — still in use and accurate in more than 80 percent of patients.

The modern form of the saliva ejector for draining a patient's mouth while dental work progresses is introduced. *See also* 1864 MED.

French physician Philippe Gaucher describes the genetic disorder now known as Gaucher disease.

✿ Physics

Women began to be admitted

to the Cavendish Laboratory in Cambridge, England, on the same terms as men. *See also* 1874 PHY.

Henry Augustus Rowland [b. Honesdale, Pennsylvania, November 27, 1848, d. Baltimore, Maryland, April 16, 1901] constructs a machine that will make precision diffraction gratings for use in advanced spectroscopy.

John William Strutt, Lord Rayleigh [b. Terling Place, England, November 12, 1842, d. Witham, Essex, June 30, 1919] discovers that the ratio of the atomic mass of oxygen to that of hydrogen is not 16-to-1 exactly, as had been assumed, but 15.882-to-1.

I Tools

Percival Everitt patents in Great Britain a machine that supplies goods when you put a coin in it.

Henry W. Seely invents the electric iron.

→ Transportation

The Saint-Gothard Tunnel is completed. The tunnel is 15 km (9.3 mi) long. The two excavation teams meet each other in the middle with an error of only 20 cm (8 in.) in the horizontal axis. *See also* 1870 TRAN.

The first attempt to build a tunnel beneath the English Channel is halted for political reasons, not technical ones. *See also* 1990 TRAN.

1883

▲ Archaeology

The Pyramids and Temples of Gizeh by English archaeologist Sir William Matthew Flinders Petrie [b. Charlton, England,

June 3, 1853, d. Jerusalem, Palestine, July 28, 1942] reveals for the first time the precision with which the Great Pyramid is aligned, only a little more than a twelfth of a degree away from a perfect north-south alignment. *See also* 2575 BCE CONS; 1887 ARCH.

Louis Julien, a French chemist, discovers the first of the so-called Venus figurines at the Grimaldi site, a cliff in Italy near Monaco overlooking the Mediterranean. The 15 figurines he finds are of women with exaggerated sexual features and sometimes pregnant and have been dated from 18,000 to 25,000 years ago.

↗ Biology

The last known quagga, a close relative of or subspecies of the plains zebra of Africa, dies in the Amsterdam zoo.

Camillo Golgi discovers "Golgi cells," a type of cell in the nervous system. *See also* 1873 BIO; 1906 BIO.

Max Rubner [b. Munich, Germany, June 2, 1854, d. Berlin, April 27, 1932] notes that metabolic rate is proportional to the surface area of an animal's body.

Animal Intelligence by George John Romanes [b. Kingston, Canada, May 19, 1848, d. Oxford, England, May 23, 1894] is the first book on comparative psychology. *See also* 1898 BIO.

▷ Chemistry

Johann Gustav Kjeldahl [b. Jagerpris, Denmark, August 16, 1883, d. Tisvildeleje, Denmark, July 18, 1900] develops a simple way to analyze the nitrogen content of organic compounds. *See also* 1850 FOOD.

Communication

George Francis Fitzgerald [b. Dublin, Ireland, August 3, 1851, d. Dublin, February 21, 1901] points out that Maxwell's theory of electromagnetic waves indicates that such waves can be generated by periodically varying an electric current. Later Hertz will demonstrate that this is true. Radio waves continue to be generated this way today. *See also* 1866 COMM; 1884 COMM.

The International Convention for patents, signed on March 20, is ratified and goes into effect in July 1884. It will be subsequently revised and extended on June 2, 1911, and November 6, 1925. The most important provision is that if a patent is granted in one member country, subsequent patents in other countries are granted as of the date of the first patent.

Construction

The ten-story Home Insurance Building is started in Chicago, Illinois. Designed by William Le Baron Jenney [b. Fairhaven, Massachusetts, September 25, 1832, d. Los Angeles, California, June 15, 1907] with a combination cast-iron and steel skeleton covered by a brick exterior, it is the first major use of steel in an office building. It is also the first tall building that has many windows, possible because the skeleton supports the structure. *See also* 1879 CONS; 1889 CONS.

Washington Augustus Roebling [b. Saxonburg, Pennsylvania, May 26, 1837, d. Trenton, New Jersey, July 21, 1926] completes his father's design of the Brooklyn Bridge,



STROLLING THE PROMENADE LEVEL OF THE BROOKLYN BRIDGE The Promenade is a walkway above the automobile lanes on the bridge. On opening day it cost a penny to walk across and about 150,000 persons did that day. Walking across the bridge is still popular in New York, with about 3000 persons crossing that way on an average day (compared to more than 140,000 vehicles).

although from 1872 on he is confined to his apartment as a result of caisson disease. His wife Emily Warren Roebling [b. Cold Spring, New York, September 23, 1843, d. 1903] acts as an intermediary, learning mathematics and engineering so that she can oversee construction. The completed bridge has a main span of 486 m (1595 ft) and is dedicated on May 24. *See also* 1869 CONS; 1931 CONS.

Earth science

Krakatoa, a volcanic island between Java and Sumatra, explodes on August 27, sending waves around the world and killing nearly 40,000 people. *See also* 1815 EAR; 1980 EAR.

Accepting an 1879 report from meteorologist and astronomer Cleveland Abbe, the United States sets up four time zones based on zones previously developed by the

railroad industry. *See also* 1891 EAR.

Energy

Stuart Perry [b. Newport, New York, November 2, 1814, d. February 9, 1890] introduces the first steel-bladed windmill. *See also* 1854 ENER; 1927 ENER.

Lucien Gaulard [b. Paris, 1850, d. November 26, 1888] of France and John Dixon Gibbs of England together introduce an induction coil

system used as an electric transformer. The coils are arranged in a series circuit. *See also* 1879 ENER; 1885 ENER.

❖ Materials

Metallurgist Robert Abbott Hadfield [b. Sheffield, England, November 29, 1858, knighted 1908, d. London, September 30, 1940] patents manganese steel, a superhard alloy that is the first of the specialty alloy steels. *See also* 1855 MATR; 1888 MATR.

Polish physicist Zygmunt Florenty von Wroblewski [b. Grodno (Belarus), October 28, 1845, d. Krakow (Poland), April 19, 1888] becomes the first to liquefy hydrogen. *See also* 1877 MATR.

Σ Mathematics

Vito Volterra [b. Ancona (Italy), May 3, 1860, d. Rome, October 11, 1940] founds functional analysis, a generalization of problems seeking functions (as in differential equations or the calculus of variations) in which, as it has developed, functions are treated as operators in abstract spaces that transform one set of points into another.

Georg Cantor's *Foundations of a General Manifold Theory* claims that every set can be made into a well-ordered set, the proof of which, supplied by Ernst Friedrich Ferdinand Zermelo [b. Berlin, July 27, 1871, d. Freiburg, Germany, May 21, 1953] in 1904, requires the controversial axiom of choice: In a well-ordered set, every subset has one member that can be identified as the first member for that subset. *See also* 1874 MATH; 1904 MATH.

♥ Medicine & health

Sir Victor Alexander Horsley [b. London, April 14, 1857, d. Amara, Turkey, July 1916] studies growth disorders and shows some that are caused by lack of thyroid secretion. *See also* 1818 MED.

Robert Koch discovers *Cholera vibrio*, the bacterium that causes cholera in humans, and shows that cholera can be transmitted by food and drinking water. *See also* 1854 MED; 1892 MED.

Sydney Ringer [b. Norwich, England, 1835, d. Lastingham, Yorkshire, October 14, 1910] discovers that an isolated frog heart kept in a saline solution will beat longer if calcium and potassium are added to the solution. The combination is known today as Ringer's solution. Ringer also finds that other activities of cells require calcium.

Francis Galton's *Enquiries into Human Faculty* introduces the term *eugenics* and suggests that human beings can be improved by selective breeding.

⌘ Physics

Edison discovers the "Edison effect," the basic principle of the vacuum tube. Edison is attempting to keep his incandescent electric bulb from turning black from carbon deposits on the glass. He introduces a metal plate into the partial vacuum inside the lamp, hoping it will draw off carbon particles. This concept does not succeed, but Edison observes that the hot lamp filament induces a current in the metal plate. Although he patents a voltage regulator based on the effect, and publicizes it, not enough is known

at this time to make a useful device from it. Others will apply it in creating the first vacuum tubes after the electron is discovered. *See also* 1904 ENER.

Osborne Reynolds [b. Belfast, Ireland, August 23, 1842, d. Watchet, Somerset, England, February 21, 1912] introduces the concept of critical velocity of a fluid; that is, the velocity at which the motion changes from laminar flow to turbulent flow. This work introduces the "Reynolds number" to physics.

→ Transportation

Konstantin Tsiolkovsky [b. Izheskoye, Russia, September 17, 1857, d. Kaluga, Soviet Union (Russia), September 19, 1935] defines his principle of rocket motion, stating that it is possible to travel through the vacuum of space with rockets. *See also* 1881 TRAN; 1895 TRAN.

Inventor Gottlieb Wilhelm Daimler [b. Schorndorf, Germany, March 17, 1834, d. Cannstatt, Württemberg, Germany, March 6, 1900] develops the first of his high-speed internal combustion engines and uses it on a boat, the first true motorboat. *See also* 1877 TRAN; 1909 TRAN.

1884

★ Astronomy

An international meeting in Washington, DC, sets the prime meridian through Greenwich, England.

⌘ Biology

Bacteriologist Hans Christian Joachim Gram [b. Copenhagen, Denmark, September 13, 1844, d. Copenhagen,

November 14, 1938] develops the dye that is used to classify bacteria into two groups, the gram-positive that retain the dye and the gram-negative that do not retain it. In the 1940s it is discovered that the two types react differently to antibiotics. *See also* 1881 BIO.

❧ Chemistry

Swante August Arrhenius [b. Vik, Sweden, February 19, 1859, d. Stockholm, October 2, 1927] proposes his dissociation theory, which says that electrolytes dissociate into positively and negatively charged ions when in solution. *See also* 1903 CHEM.

⌚ Communication

Lewis E. Waterman [b. Decatur, New York, 1837, d. 1901] patents the modern type of fountain pen. *See also* 1938 COMM.

William Preece [b. Bryn Helen, Wales, February 15, 1834, d. Penrose, Wales, November 6, 1913] notices that overhead telegraph wires can pick up messages carried by underground wires. This observation leads him to collaborate with Guglielmo Marconi on wireless transmission. *See also* 1883 COMM; 1902 COMM.

Ottmar Mergenthaler [b. Hachtel, Germany, May 11 1854, d. Baltimore, Maryland, October 18, 1899] invents the Linotype typesetting machine. The machine is equipped with a keyboard like a typewriter and casts a single line of type at a time as a solid bar. *See also* 1840 COMM; 1887 COMM.

George Eastman and William H. Walker introduce the use of roll film into photography. The negative images, obtained

on paper, have to be mounted on glass for reproduction. *See also* 1864 COMM; 1889 COMM.

Telephone wires connect Boston to New York. *See also* 1880 COMM.

Paul Nipkow [b. Liauenberg, Germany, August 22, 1860, d. Berlin, August 24, 1940] invents the scanning disk named after him, a precursor of television. The rotating disk has a hole through which a narrow beam of light from the object passes. Its intensity is measured by a selenium photocell which then modulates another source of light that passes through a hole in an identical rotating disk. The second source of light reproduces the image. *See also* 1926 COMM.

■ Construction

The Washington Monument is completed. *See also* 1450 BCE CONS.

❖ Ecology & the environment

California prohibits using water to extract ores because of the pollution of agricultural land the waste water causes.

❖ Energy

Nikola Tesla invents the electric alternator, an electric generator that produces alternating current. In alternating current (a.c.), the electrons flow first in one direction and then in the other, unlike direct current (d.c.), with electron flow in a single direction.

Many devices, including electric lights and motors, work as well or better with a.c. current, which, unlike d.c. current, can be transmitted long distances over wires with little loss of energy. (Some devices need d.c. current, but transformers

easily change a.c. into d.c.). *See also* 1867 ENER; 1887 ENER.

Charles Algernon Parsons [b. London, June 13, 1854, d. on shipboard off Kingston, Jamaica, February 11, 1931] patents the first steam turbine generator for use in ships. The first turbine of the multicellular design will be built in 1885. It rotates at a satisfactory 18,000 revolutions per minute, although it produces only 7.5 kW (10 hp). *See also* 1880 ENER; 1888 ENER.

American carpenter Lester Allan Pelton [b. Vermillion, Ohio, September 5, 1829, d. Oakland, Ohio, March 14, 1908], as a result of observing a misplaced bucket on a water wheel at a California gold mine, invents the Pelton wheel, a type of water turbine with blades shaped like divided buckets so that the direction of a water jet directed on them is reversed entirely, thus using a maximum of the kinetic energy of the jet.



Nikola Tesla

[b. Smiljan (Croatia), July 10, 1856, d. New York, January 7, 1943]

Tesla's successes came in the 1880s and 1890s with his invention of an electric motor that runs on alternating current and transformers that make long-distance transmission of electric power possible. In the 20th century he worked on problems of transmitting electric power without wires, an idea that failed to have any significant impact.

❖ Materials

Louis-Marie-Hilaire Bernigaud, comte de Chardonnet [b. Besançon, France, March 1, 1839, d. Paris, March 25, 1924] begins to produce an artificial fiber made from cel-

lulose, which comes to be known as rayon. *See also* 1855 MATR; 1889 MATR.

Carl Zeiss [b. Weimar, Germany, September 11 1816, d. Jena, Germany, December 3, 1888] develops a type of glass that resists heat. The resistance is conferred by adding boric acid to the silicon-dioxide mixture used to make glass. *See also* 1915 MATR.

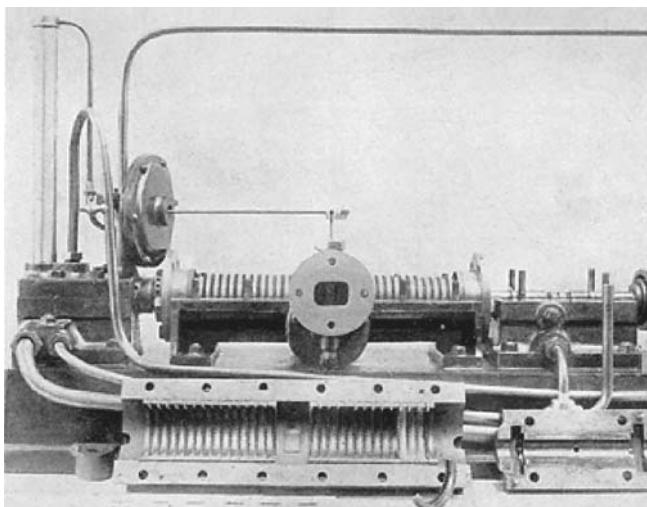
P. Böttiger discovers the dye congo red (bis-azo), the first dye that can be used on cellulose fibers without preparing the fiber with treatment by another chemical. *See also* 1856 MATR; 1897 CHEM.

German organic chemist Otto Wallach starts a long project of isolating terpenes from various essential oils, such as menthol and camphor. His work forms the basis for much of the perfume industry. *See also* 1879 MATR; 1910 CHEM.

French chemist Paul Vielle [b. Paris, 1854, d. Paris, 1934] develops the first smokeless gunpowder that is reliable enough for military purposes. Previous smokeless gunpowders had been useful only in shotguns. *See also* 1889 MATR.

Σ Mathematics

Gottlob Frege's *Die Grundlagen der Arithmetik* ("foundations of arithmetic") bases all of natural-number arithmetic on his definition of a natural number (natural numbers are simply the counting numbers, 1, 2, 3, etc.) as the class of all classes that can be put into one-to-one correspondence with a given class. For example, 5 would be defined as every class (or set) that exactly matches the number of fingers on the normal human hand. *See also* 1889 MATH.



FIRST PARSONS' STEAM TURBINE Parsons decided that he could obtain a rotation speed that would be suitable for most uses by having a series of small turbines instead of a single large one — what is termed a multi-cellular design. The same principle had already been shown to be successful for hydraulic turbines.

♥ Medicine & health

Russian-French bacteriologist Ilya Illich Mechnikov [b. Ivanovka, Ukraine, May 16, 1845, d. Paris, July 15, 1916] discovers phagocytes, moving white blood cells that attack and devour invading organisms in the body. *See also* 1908 MED.

Physiologist Max Rubner discovers that the body gets energy from carbohydrates, fats, and proteins (after stripping away the nitrogen from proteins for other uses). *See also* 1894 BIO.

Edwin Klebs [b. Prussia (Germany), February 6, 1834, d. Berne, Switzerland, October 23, 1913] and Friedrich Löffler discover the bacillus that causes diphtheria and that some animals are naturally immune to the disease. *See also* 1888 MED.

Charles Chamberland develops special porcelain filters for

bacteria that help purify water and also lead to the discovery that toxins produced by bacteria cause such diseases as diphtheria and tetanus. Later his filters will lead to the discovery of viruses. *See also* 1892 BIO.

Czech-American surgeon Carl Koller [b. Schüttenhofen, Bohemia (Czech Republic), December 3, 1857, d. New York, March 21, 1944] uses cocaine as a local anesthetic. *See also* 1846 MED; 1890 MED.

✿ Physics

Ludwig Boltzmann calculates the heat radiation emitted by a heated body and shows that nonblack bodies always radiate less light than black bodies (perfect absorbers). *See also* 1879 PHY; 1896 PHY.

I Tools

Hiram Maxim develops the Maxim machine gun, a single-barrel, belt-fed, water-cooled

weapon that fires 600 shots per minute. It is adopted by the British army in 1889 and thereafter by many other armies and navies. *See also* 1862 TOOL; 1920 TOOL.

John Patterson [b. 1844, d. 1922] buys the rights to Ritty's Incorruptible Cashier and forms the National Cash Register Company. An aggressive sales campaign results in sales of a million cash registers by 1911. *See also* 1879 TOOL.

✈ Transportation

Frank Julian Sprague [b. Milford, Connecticut, July 25, 1857, d. October 25, 1934] develops a direct-current motor for electric locomotives. *See also* 1881 TRAN.

The airship *La France*, designed, built, and piloted by Charles Renard [b. Damblain, France, 1847, d. Paris, 1905] and Arthur C. Krebs [b. 1847, d. 1935], on August 9 becomes

the first dirigible, an airship capable of being steered well enough to return to its launch point after a flight of about 8 km (5 mi). *La France* is powered by an electric motor.

1885

★ Astronomy

A supernova appears in M31, the Andromeda Galaxy. This will be the only recorded extragalactic supernova to reach the fringe of naked-eye visibility until the supernova of 1987. *See also* 1604 AST; 1987 AST.

Uranometria nova oxoniensis ("new Oxford Uranometria") by British astronomer Charles Pritchard [b. Alberbury, England, February 29, 1808, d. May 28, 1893] catalogs stars using his invention of the wedge photometer to measure their relative brightness. *See also* 1882 AST.

The feminine brain (a 19th century view)

Many great men of science had a low opinion of women. Aristotle, who used "pure logic" to infer that women have fewer teeth than men but never bothered to count women's teeth, said that women are passive and men active. He considered women as "mutilated men." Darwin and Freud also believed in the innate inferiority of women, and during the 19th century many scientists were convinced that women had to be less intelligent because of differences in brain structure.

In 1861 the famous French physical anthropologist Paul Broca weighed the brains of deceased men and women in four Parisian hospitals and concluded that the brains of women, on the average, were 200 g (7 oz) lighter than the brains of men. Gustave Le Bon, a student of Broca, claimed that the brain of a woman was in size "closer to the brain of the gorilla than the brain of men."

And according to Le Bon, "all psychologists who have studied the intelligence of women recognize that they represent an inferior form of evolution and that they are closer to the child and the savage."

Some scientists from the 19th century were convinced that intelligence was located in the frontal lobe of the brain, and therefore believed that women should have smaller frontal lobes. The year 1884 saw the publication of a scientific book in which woman is called *Homo parietalis* and man is called *homo frontalis*.

It was soon found, however, that the frontal lobes in women were generally larger than those of men, and therefore male scientists concluded that not the frontal lobe but the parietal lobe of the brain should be the seat of intelligence.

In the early 20th century scientists found that the size of the brain had nothing to do with intelligence, disproving all those learned theories from the 19th century as pure nonsense. Women are generally smaller than men, so they have smaller brains, but not smaller intelligence.

Biology

Horace Darwin [b. Down House, England, 1851, d. 1928] (the youngest son of Charles Darwin, author of *Origin of Species*) designs the rocking microtome, an apparatus to make thin slices of specimen to be observed by the microscope. The first microtomes were invented by Robert Hooke although the name *microtome* was not used until 1839. Darwin's rocking microtome quickly replaces all earlier types and will remain popular.

Paul Ehrlich discovers the blood-brain barrier, which prevents many substances dissolved in blood from reaching the brain.

Camillo Golgi and others elucidate the asexual cycle of the malaria parasite. *See also* 1880 MED; 1892 MED.

Chemistry

Lehrbuch der allgemeinen Chemie ("textbook of universal chemistry") by Friedrich Wilhelm Ostwald [b. Riga (Latvia), September 2, 1853, d. Leipzig, Germany, April 4, 1932] is considered to mark the founding of physical chemistry.

Jacobus Van't Hoff develops his formula for osmotic pressure: The osmotic pressure of dilute solutions depends on the concentrations of the dissolved molecules. *See also* 1748 PHY; 1901 CHEM.

Clemens Alexander Winkler [b. Freiberg, Germany, December 26, 1838, d. Dresden, Germany, October 8, 1904] discovers germanium (Ge), the third element predicted by Mendeléev on the basis of his periodic table. *See also* 1871 CHEM.

Karl Auer, later Baron von Welsbach [b. Vienna, Austria, September 1, 1858, d. Welsbach Castle, Austria, August 8, 1929] discovers that one supposed element is actually two. He names one element neodymium ("new twin") (Nd) and the other praseodymium ("green twin," for the color of its spectrum) (Pr).

Communication

Charles S. Tainter [b. Watertown, Massachusetts, April 25, 1854, d. April 20, 1940] develops the Dictaphone, a machine for recording dictation. *See also* 1877 COMM.

Frederic E. Ives invents the modern method called halftone printing for screened photographs, a different and much improved method from the one he used earlier. Results of the two methods are alike, but the new method is much less complicated. *See also* 1881 COMM.

Computers

Dorr Felt [b. Beloit, Wisconsin, March 18, 1862, d. Chicago, August 7, 1930] develops the Comptometer, a key-driven adding and subtracting machine. *See also* 1889 COMP.

Earth science

Lord Rayleigh identifies the type of earthquake waves now called Rayleigh waves. These are surface waves as opposed to the S and P waves that propagate through the body of Earth. *See also* 1880 EAR.

The first volume of *Das Antlitz der Erde* ("the face of the Earth") by Austrian geologist Eduard Suess [b. London, August 20, 1831, d. Marz, Austria, April 26, 1914] is published. This five-volume work,

completed in 1909, attempts to explain such geological features as mountain changes in terms of Earth's contraction as it cools (no longer thought to be correct).

Ecology & the environment

The first U.S. garbage incinerator is installed on Governors Island in New York Harbor.

Energy

James Prescott Joule builds an internal combustion engine based on the incomplete ideal Carnot cycle that uses a porous piston through which the exhaust escapes. This engine is on the line of development that eventually leads to the diesel. *See also* 1890 ENER.

Leonart Jennett Todd patents a steam engine with a so-called "terminal exhaust" cylinder. It has two hot inlets and a common central cold exhaust. The cylinder acts as the exhaust valve. The engine is more efficient than previous steam engines because the cylinder is kept hot at both ends. This type of design later becomes known as the uniflow engine because steam flows in one direction through the cylinder. *See also* 1827 ENER.

Gottlieb Daimler patents his four-cycle internal combustion engine with compression, a surface carburetor, and a magneto for ignition. *See also* 1877 ENER; 1893 ENER.

Food & agriculture

John B. Meyenberg, a German immigrant living in Highland, Illinois, introduces canned evaporated milk.

Bordeaux mixture (a combi-

nation of copper sulfate and hydrated lime dissolved in water) is discovered by French horticulturist Pierre Marie Alexis Millardet [b. Monmery-la-Ville, France, December 13, 1838, d. Bordeaux, France, December 15, 1902] to control a serious fungus disease of grapes. Invented by wheat farmers to prevent a fungus disease of seed, Bordeaux mixture is blue-green from the copper sulfate and had been applied to the grapes in Bordeaux to discourage grape thieves. Bordeaux mixture is quickly discovered to control other fungal diseases, such as late potato blight (the cause of the Irish famine of 1845–46). It is still used today. *See also* 1845 FOOD; 1896 FOOD.

Materials

French chemist Eugène Turpin discovers how to load artillery shells with picric acid, which explodes on impact (a "bursting charge"). *See also* 1871 MATR.

Medicine & health

Louis Pasteur develops a vaccine against hydrophobia (rabies) and uses it to save the life of a young boy, Joseph Meister, bitten by a rabid dog. *See also* 1881 MED; 1890 MED.

Swiss surgeon Emil Kocher develops surgical removal of the thyroid as a cure for goiter about this time. *See also* 1891 MED; 1909 MED.

Austrian psychiatrist Sigmund Freud [b. Freiberg, Germany, May 6, 1856, d. London, September 23, 1939] studies hypnotism with Jean Martin Charcot, the beginning of his path toward the development of psychoanalysis. *See also* 1880 MED.

Über das Gedächtnis ("on memory") by Hermann Ebbinghaus [b. Wuppertal, Germany, January 24, 1850, d. Halle, Germany, February 26, 1909] contains his "curve of forgetting," which reflects how much information is retained in human memory with time.

French neurologist Pierre Marie [b. Paris, September 9, 1853, d. April 13, 1940] describes acromegaly (sometimes called Marie's disease), a hormone disorder caused by overproduction after puberty of human growth hormone by the pituitary gland, resulting in excess growth of bones and other tissues. The hands, feet, and parts of the face grow out of proportion to the rest of the body. The most common cause is a tumor on the pituitary. *See also* 1855 MED; 1889 MED.

❖ Physics

Johann Jakob Balmer [b. Lausen, Switzerland, May 1, 1825, d. Basel, March 12, 1898] discovers the formula for the hydrogen spectrum that will later inspire Niels Bohr to develop his model of the atom. *See also* 1871 PHY; 1890 PHY.

➤ Transportation

The Rover Company, following the concepts of Harry Lawson, is the first to manufacture a vehicle that would be recognized today as an ordinary bicycle (except that it lacks air-filled rubber tires). *See also* 1876 TRAN; 1888 TRAN.

Gottlieb Daimler installs one of his internal combustion engines on a bicycle, creating the world's first motorbike. *See also* 1883 TRAN.

Karl Benz builds a three-wheel automobile powered by a

gasoline engine. *See also* 1878 ENER; 1886 TRAN.

1886

◀ Anthropology

The second discovery of skeletons of the Neandertal type occurs. *See also* 1856 ANTH.

The last full-blooded Tasmanian, a woman named Truganini, dies. Although Europeans had murdered most of the other Tasmanians, they also had interbred with them, so there remains a Tasmanian heritage on the island. *See also* 1772 TOOL.

★ Astronomy

Henry Rowland uses diffraction gratings prepared by his improved method to map the solar spectrum, giving the precise wavelength to about 14,000 lines in the spectrum.

□ Chemistry

Francois Marie Raoult [b. Fournes-en-Weppe Nord, France, May 10, 1830, d. Grenoble, Isère, France, April 1, 1901] introduces the law named for him — that the lowering of the vapor pressure of a solvent is proportional to the concentration of the substance dissolved, unless the solvent is an electrolyte.

After many unsuccessful and dangerous attempts by other chemists, Ferdinand Frédéric Henri Moissan [b. Paris, September 28, 1852, d. Paris, February 20, 1907] succeeds on June 26 in isolating the element fluorine (F). Fluorine's poisonous nature is believed to have contributed to Moissan's early death at age 54. *See also* 1906 CHEM.

Swiss chemist Jean-Charles

Galissard de Marignac [b. Geneva, Switzerland, April 24, 1817, d. Geneva, April 15, 1894] discovers gadolinium (Gd).

Paul-Emile Lecoq de Boisbaudran discovers the element dysprosium (Dy).

◀ Communication

Alexander Graham Bell uses shellac cylinders for recording sound with a modified version of Edison's phonograph, which he calls the gramophone *See also* 1877 COMM; 1888 COMM.

French criminologist Alphonse Bertillon [b. Paris, April 23, 1853, d. Paris, February 13, 1914] develops the system of identification named for him. The Bertillon system uses various physical characteristics, especially head length, that are difficult to change to identify individuals, especially criminals; fingerprints are included as part of the system. *See also* 1880 COMM; 1901 COMM.

■ Construction

Gustave Eiffel [b. Dijon, France, December 15, 1832, d. Paris, December 27, 1923] starts building the tower named after him. It is assembled from 12,000 prefabricated metal parts and is built over two years without any worker's loss of life. *See also* 1889 CONS.

Thomas Crapper [b. England, September 1836, d. January 27, 1910] invents what amounts to a modern form of flush toilet, with the tank of reserve water a good height above the bowl and a chain and lever system that allows a charge of water to both expel and dilute the material in the

bowl. He also includes a bend in the pipe leading to the sewer so that there is only clean water in the pipe after the fouled water passes on to the sewer. *See also* 1778 CONS; 1889 CONS.

⊕ Earth science

A major earthquake strikes Charleston, South Carolina. Although measuring only 6.5 to 7.0 on the Richter scale, its effects are felt strongly as far away as Chicago because the rock structure of the eastern part of the United States transmits earthquake waves more efficiently than does that of the west. *See also* 1880 EAR.

■ Food & agriculture

Hermann Hellriegel [b. Mausitz, Saxony, Germany, October 21, 1831, d. Bernburg, Anhalt-Bernburg, Germany, September 24, 1895] announces his discovery that legumes remove nitrogen from the air, unlike other most plants, which must use nitrogen fixed in compounds in the soil. Later it will be shown that specialized bacteria on the roots of legumes actually fix the nitrogen. *See also* 1850 FOOD; 1908 MATR.

John S. Pemberton [b. Philadelphia, August 10, 1814, d. August 16, 1888] invents Coca-Cola. Instead of patenting his product, he keeps the formula secret. It remains protected under the trade-secret protection legislation to this day.

◊ Materials

Hamilton Young Castner [b. Brooklyn, New York, September 11, 1858, d. Saranac Lake, New York, October 11, 1899] invents the sodium process of aluminum production.

Charles M. Hall [b. Thompson, Ohio, December 6, 1863, d. Daytona Beach, Florida, December 27, 1914] and Paul-Louis-Toussaint Héroult [b. Thury-Harcourt, Calvados, France, April 10, 1863, d. near Antibes, May 9, 1914] independently discover an economical way to make aluminum from abundant alumina and electric power. *See also* 1887 MATR.

♥ Medicine & health

Psychopathia sexualis by neurologist Baron Richard von Krafft-Ebing [b. Mannheim, Germany, August 14, 1840, d. Mariagrun, Austria, December 22, 1902] is the first account of abnormal sexual practices in humans and introduces such terms as *paranoia*, *sadism*, and *masochism*.

Ernst von Bergmann [b. Riga, (Latvia), December 16, 1836, d. March 25, 1907] introduces steam sterilization of surgical instruments in his Berlin clinic. *See also* 1890 MED.

Three French physicians discover the hereditary neuropathy now named after them, Charcot-Marie-Tooth disease, which involves progressive wasting and weakness of muscles in arms and feet.

⌘ Physics

Eugen Goldstein observes that a cathode-ray tube produces, in addition to the cathode ray, radiation that travels in the opposite direction — away from the anode (called a canal ray because of holes bored in the cathode). Later canal rays will be found to consist of ions that have had electrons stripped in producing the cathode ray. *See also* 1878 comm/ 1897 PHY.

William Crookes proposes that atomic weights measured by chemists are averages of the weights of different kinds of atoms of the same element (although it will not be until 1910 that Soddy identifies these different kinds of atoms as isotopes). Crookes suggests that the elements are built up of more elementary substances with masses that are multiples of the mass of hydrogen atoms. *See also* 1865 CHEM; 1920 PHY.

Physical chemist Hendrik Willem Bakhuys-Roozeboom [b. Alkmaar, Netherlands, October 24, 1854, d. Amsterdam, Netherlands, February 8, 1907] learns of the mathematical phase rule of Josiah Gibbs, an equation connecting the solid, liquid, and gaseous phases of a substance that also explains many other rules that had been experimentally discovered. In the next few years Bakhuys-Roozeboom establishes the rule experimentally for the first time and also publicizes it widely in Europe, where Gibbs is little known. *See also* 1880 PHY.

I Tools

Elihu Thomson patents a welding method using heating by electrical resistance. *See also* 1898 MATR.

→ Transportation

On March 8 Gottlieb Daimler and Wilhelm Maybach [b. Heilbronn, Germany, February 9, 1846, d. Stuttgart, Germany, December 29, 1929] build a four-wheeled vehicle propelled by an internal combustion engine. Its design is based on the three-wheeled automobile built by Karl Benz; but it is viewed as the prototype of the modern

automobile. *See also* 1885 TRAN; 1902 TRAN.

1887

▲ Archaeology

Augustus Henry Lane Fox Pitt-Rivers [b. Hope Hall, Yorkshire, England, April 14, 1827, d. Rushmore, Wilshire, England, May 4, 1900] publishes the first of four volumes of *Excavations in Cranborne Chase*, describing his method of methodically excavating trenches and cataloging every artifact and bone, a method that eventually will become standard, along with the results of his archaeological study of an ancient Roman and pre-Roman site in England. The last volume appears in 1898. *See also* 1784 ARCH.

Flinders Petrie begins his excavation of the pyramid of Senusret II. *See also* 1883 ARCH.

★ Astronomy

The Lick 91-cm (36-in.) refracting telescope is completed and installed on Mount Hamilton near San Francisco, California, on December 31. It is the world's first mountaintop telescope. *See also* 1894 AST.

Sir William de Wive-Leslie Abney [b. Derby, England, July 24, 1843, d. Folkestone, England, December 2, 1920] develops methods to detect infrared radiation with photographs and uses them to observe the spectrum of the Sun. *See also* 1858 AST; 1891 AST.

↗ Biology

Édouard Joseph Louis-Marie van Beneden [b. Louvain, Belgium, March 5, 1846, d. Liège,

Belgium, April 28, 1910] discovers that each species has a fixed number of chromosomes and also observes for the first time the formation of "haploid cells" (cells with half the original number of chromosomes) during cell division of the sperm and ova (meiosis). *See also* 1875 BIO; 1888 BIO.

▷ Chemistry

Emil Hermann Fischer [b. Euskirchen, Rhenish Prussia, Germany, October 9, 1852, d. Berlin, July 15, 1919] analyzes the structure of sugars. *See also* 1902 CHEM.

↳ Communication

Tolbert Lanston [b. Troy, Ohio, March 2, 1844, d. 1913] patents the Monotype typesetting machine. *See also* 1884 COMM; 1949 COMM.

Western Union is the first to apply multiplexing on telephone lines by using very low frequencies for the transmission of telegraphic signals along with different frequencies for the transmission of voice. *See also* 1874 COMM.

Rev. Hannibal W. Goodwin [b. Tompkins County, New York, April 21, 1822, d. December 31, 1900] invents the celluloid photographic film and develops a production process for it. *See also* 1869 MATR; 1889 COMM.

■ Construction

Anna Connelly patents the fire escape.

↗ Energy

In November and December, Nikola Tesla patents an alternating current (a.c.) induction motor as well as a.c. transformers, power lines, and gen-



LICK OBSERVATORY ON MOUNT HAMILTON At 1281 m (4206 ft), Mount Hamilton is far from the highest mountain in the United States, but it was still an undeveloped mountain top when James Lick chose it as the site of the world's first mountain-top observatory. There is still an operating Lick Observatory atop Mount Hamilton (with new equipment) and much of the region around the mountain is still wilderness, preserved by the Nature Conservancy.

erators, the basis of a complete system for a.c. electricity grids. Although Thomas Edison will fight for his direct current (d.c.), the superior transmission capability of a.c. will win the day and become the main system in use around the world. *See also* 1884 ENER; 1893 ENER.

Mansfield Merriman [b. Southington, Connecticut, March 27, 1848, d. New York, June 7, 1925] founds the first experimental laboratory for hydraulics. *See also* 1882 COMM; 1898 CONS.

Karl Auer invents the mantle for gas lamps, a cotton net soaked in thorium oxide that emits an extremely white light when heated by a Bunsen burner (similar to the Coleman white-gas lamps often used by campers today). *See also* 1879 ENER.

Carl Gustav de Laval develops a small steam turbine rotating at 42,000 revolutions per

minute. *See also* 1884 ENER; 1888 ENER.

Carl Gassner of Germany develops the dry version of the zinc-carbon battery. This is essentially the dry-cell battery used today. *See also* 1866 ENER; 1900 ENER.

❖ Materials

Alfred Nobel develops ballistite, the first smokeless blasting powder, but in Great Britain, a very similar material, called cordite, will be invented in 1889. The patents for ballistite and cordite will be contested in 1894 and 1895, and the British courts will rule against Nobel. *See also* 1875 MATR; 1889 MATR.

♥ Medicine & health

Louis J. Girard of Baylor College of Medicine in Houston, Texas, and independently German physiologist Adolf Fick and glass-blower F.A. Muller develop the first form of contact lens, which covers the

whites of the eye as well as the cornea. The corneal contact lens will be developed by an American optician who accidentally breaks off the corneal part of the lens as he is making the older version. *See also* 1948 MED.

✿ Physics

Albert Michelson and Edward Williams Morley [b. Newark, New Jersey, January 29, 1838, d. West Hartford, Connecticut, February 24, 1923] measure the velocity of light in two directions, attempting to detect the proper motion of Earth through the ether. The Michelson-Morley experiment confirms the absence of an ether. *See also* 1881 TOOL; 1907 PHY.

Ernst Mach revives the idea that science only gives information that is supplied by the senses, and that the ultimate nature of reality is beyond the reach of our intelligence. *See also* 1903 PHY.



Heinrich Hertz

[b. Hamburg, Germany, February 22, 1857, d. Bonn, Germany, January 1, 1894]

The equations for electromagnetism that James Clerk Maxwell developed from 1856 to 1873 showed that an electromagnetic wave is caused by the oscillation of an electric charge and propagates at the speed of light. Maxwell speculated (correctly) that light is an electromagnetic wave and that other forms of radiation have shorter or longer wavelengths. Hertz set out to create an electromagnetic wave with an apparatus that developed an oscillating spark. In 1888 he produced, detected, and identified what we now call radio waves. Hertz also observed that his device made better sparks when exposed to ultraviolet radiation, a result of the photoelectric phenomenon caused by energetic photons knocking electrons off a metal surface.

Does the ether exist?

In 1881 Albert A. Michelson and Edward Morley tried to measure the absolute velocity of Earth with respect to the rest of the universe. The result of their measurement showed that Earth is at rest in space, but no one believed that that could be true. The idea of a motionless Earth had been given up 300 years earlier. Something had to be wrong with the experiment.

The problem at first glance seemed to be with light. Ever since Thomas Young had demonstrated in 1803 that light produces interference patterns, it was assumed that light must be waves, a view previously held by Christiaan Huygens and others. All those who espoused the wave theory — the alternative theory was that light consisted of particles — assumed that light must be waves in something. When Augustin-Jean Fresnel began to work on the wave theory of light, he named the something ether, after Aristotle's fifth element. Fresnel was able to show that light waves are more like water waves (but in three dimensions instead of just up and down) than they are like sound waves (which are back and forth instead of up and down).

Michelson had taken a suggestion of James Clerk Maxwell, made in 1875, to develop a sensitive measuring tool based on the interference patterns of waves of light. The Michelson-Morley experiment was designed to use the interferometer, Michelson's new tool, to measure how Earth moves through the ether, which was assumed to be stationary. Michelson and Morley measured the speed of light in two perpendicular directions. The speed was found to be the same, implying that Earth stands still.

Others had different explanations. Both George Francis Fitzgerald and Hendrik Antoon Lorentz suggested that the problem could be resolved by assuming that objects contract when they move. By assigning the correct value to the contraction, the speed of light could be made to appear the same in two different directions, since the apparatus used to measure it would contract in the direction in which Earth is moving.

In 1905 Albert Einstein resolved the issue in a different way. Einstein perceived that the same physical laws must be true in all frames of reference in steady motion with respect to each other. But this requirement also means that light must have the same speed no matter how a body is moving. There can be no fixed frame of reference against which Earth moves, so Michelson and Morley got the correct result. In addition, the Fitzgerald-Lorentz contraction is a real effect, explained by Einstein's theory. Furthermore, in a separate paper, Einstein showed that light behaves like a particle as well as like a wave. Although this wave-particle duality remains difficult to picture, it has become quite clear since 1905 that light has both wave and particle properties. A particle does not require a medium the way that a wave does.

Does the ether exist? Einstein's theory of special relativity suggests that the question is irrelevant. Certainly no one thinks today that a solid medium pervades space. On the other hand, it is widely believed that there is no real vacuum. Arno Penzias and Robert Wilson detected in 1964 the cosmic background radiation, a leftover of the big bang. This radiation is pervasive and basically the same in all directions. It is possible to measure Earth's movement against this background radiation. As it turns out, Earth moves.

The effect of light on a spark gap, the first hint of the photoemissive effect, is discovered by Heinrich Hertz, who observes that ultraviolet light affects the length of the spark. The photoemissive effect is the form of photoelectric effect in which electrons are emitted from a metal struck by light. It is sometimes confused with a different photoelectric effect, the change in conductivity caused by light, which is the photovoltaic effect. See also 1888 PHY.

I Tools

George Barnard Grant [b. December 21, 1849, d. Pasadena, California, August 16, 1917] introduces the first successful machine for cutting

gears using a device called a hob; it is fed across the revolving gear blank. Gears are still made with the descendants of this machine and of the gear shaper of about a decade later. See also 1861 TOOL; 1896 TOOL.

→ Transportation

Ernst Mach publishes photographs that show the shock wave that develops at supersonic speeds. This work leads engineers to designate the ratio of speed of a vehicle or projectile to the speed of sound as the Mach number, with Mach 1 being the speed of sound in the atmosphere at then current conditions of pressure, temperature, and so forth. See also 1947 TRAN.

Siemens & Halske introduces the electrically driven elevator at the industrial exhibition in Mannheim, Germany. See also 1867 TRAN.

1888

▲ Archaeology

On December 18 Colorado rancher Richard Wetherill [b. 1858, d. 1910] discovers Cliff Palace, the largest of the cliff dwellings at Mesa Verde, containing about 150 rooms and 23 kivas (round buildings used for religious ceremonies). See also 1874 ARCH.

★ Astronomy

Hermann Vogel [b. Leipzig, Germany, April 3, 1841, d.

Potsdam, Germany, August 13, 1907] makes the first systematic spectrographic measurements of the radial velocities of stars — the speeds at which stars are moving away from Earth — using Armand Fizeau's principle of the redshift (also known as the Doppler effect). See also 1868 AST.

A *New General Catalogue of Nebulae and Clusters of Stars* written by Johann Louis Emil Dreyer [b. Copenhagen, Denmark, February 13, 1852, d. Oxford, England, September 14, 1926] is published. The designation NGC for an astronomical object — for example, the galaxy NGC 6240 — refers to this catalog, which

contains 7840 “nebulæ” (many actually galaxies) and star clusters. *See also* 1786 AST.

Biology

Theodor Boveri [b. Bamberg, Germany, October 12, 1862, d. Würzburg, Germany, October 15, 1915] discovers and names the centrosome, the small body that appears during cell division and seems to control the process.

Anatomist Heinrich Wilhelm Gottfried (von) Waldeyer-Hartz [b. Braunschweig, Germany, October 6, 1836, d. Berlin, January 23, 1921] coins the word *chromosome*. *See also* 1887 BIO; 1892 BIO.

Chemistry

Austrian botanist Friedrich Reinitzer [b. 1857, d. 1927] discovers the first liquid crystal, cholesteryl benzoate. *See also* 1889 CHEM.

Friedrich Ostwald discovers that catalysts affect only reaction speed and not reaction equilibrium. *See also* 1854 CHEM; 1909 CHEM.

Communication

Edison and his lab assistant William Kennedy Laurie (W.K.L.) Dickson [b. Minihic-sur-Ranse, France, 1860, d. Twickenham, Middlesex, England, 1935] make a sound “motion picture.” A phonograph with the sound recording controls a cylinder with a series of photographs on it (called a Kinetoscope by Edison) for synchronization of sound and image. The photographs are viewed through a magnifying lens and, as in later cinema and television, persistence of vision gives the illusion of motion. A description is filed with the U.S.

Patent Office on October 8. *See also* 1891 COMM.

In June George Eastman introduces the first commercial paper roll-film camera, a box camera that he names the Kodak. It costs \$25 and takes 100 pictures; you return the entire camera with film inside for processing. This is a high price, and the original Kodak is something of a luxury item. *See also* 1884 COMM; 1889 COMM.

Mechanical engineer Oberlin Smith [b. 1840, d. 1926] describes in an American journal a magnetic sound recording system, a precursor of today’s magnetic tape recorder. *See also* 1893 COMM.

Tanner John J. Loud patents a pen to mark leather with a rotating writing ball, a fore-runner of the ballpoint pen. *See also* 1884 COMM; 1895 COMM.

German-American inventor Emile Berliner [b. Hanover, Germany, May 20, 1851, d. Washington, DC, August 3, 1929] invents the flat disk form of the phonograph record, an improvement over Edison’s wax or Bell’s shellac cylinder system that is quickly adopted by the record industry. Berliner adapts Bell’s shellac process (entering a form of partnership with him) but also finds a way to etch the grooves chemically, making it possible to mass produce recordings. The new device is called the gram-o-phone (later spelled gramophone). *See also* 1877 COMM.

Computers

William S. Burroughs [b. Rochester, New York, January 28, 1855, d. Citronelle, Alabama, September 14, 1898]

patents an adding machine. *See also* 1885 COMP; 1889 COMP.

Construction

On August 7 in Philadelphia Theophilus Van Kannel patents the revolving door.

Earth science

The first seismograph in the United States is installed at the Lick Observatory in California. *See also* 1880 EAR.

Explorer Fridtjof Nansen [b. Store-Frøen, Norway, October 10, 1861, d. Lysaker, Norway, May 13, 1930] and his team of explorers become the first people to cross Greenland by land.

Energy

The first Parsons steam turbine driving an electric generator is installed at Forth Banks in England. *See also* 1884 ENER; 1895 ENER.

Carl Gustav de Laval invents the impulse turbine. *See also* 1887 ENER; 1890 ENER.

Charles Van Depoele [b. Lichtervelde, Belgium, April 27, 1846, d. Lynn, Massachusetts, March 18, 1892] introduces carbon contacts instead of metallic brushes to drain current from commutators, reducing sparking substantially. *See also* 1877 ENER.

Food & agriculture

Emile Christian Hansen [b. Ribe, Denmark, May 8, 1842, d. Copenhagen, August 27, 1909] isolates a pure culture of the yeast *Saccharomyces carlsbergensis* (named after the Carlsberg brewery) and introduces the practice of bottom fermentation with it, which will be adopted by breweries

to produce lager beer. *See also* 1856 BIO.

Materials

Chemist George W. Kahlbaum [b. Berlin, April 8, 1853, d. Basel, Switzerland, August 28, 1905] fabricates plastic bottles from metacrylate, one of the first uses of plastics. *See also* 1975 MATR.

William J. Keep [b. Oberlin, Ohio, June 3, 1842, d. September 30, 1918] discovers that the various types of cast iron identified by workers in the industry are determined by the amount of silicon in the alloy. *See also* 1883 MATR.

Ernst Abbe and Otto Schott [b. Witten, Germany, December 17, 1851, d. Jena, Germany, August 27, 1935] develop barium glass, which has a very high refraction index and which allows the construction of achromatic lenses. *See also* 1884 MATR.

Mathematics

Marius Sophus Lie and Friederich Engel [b. Lügau, Germany, December 26, 1861, d. Giessen, Germany, September 29, 1941] begin publication of their three-volume *Theorie der Transformationengruppen* (“theory of transformation groups”), which will be completed in 1893. The mathematical ideas are largely owed to Lie, but the expression of them in a clear fashion is a result of Engel’s collaboration. *See also* 1873 MATH.

Sonya Kovalevsky receives the Prix Bourdin from the French Academy for her paper “On the Rotation of a Solid Body about a Fixed Point” (submitted anonymously because of concern about prejudice against women in mathematics).

Richard Dedekind's *Was sind und was sollen die Zahlen* ("the nature and meaning of numbers") introduces the definition of an infinite set as a set that can be put into one-to-one correspondence with a proper subset of itself; it remains the most common definition. *See also* 1877 MATH.

♥ Medicine & health

Bacteriologist Pierre Paul Émile Roux [b. Charente, France, December 17, 1853, d. Paris, November 3, 1933] and Alexandre Yersin [b. Lavaux, Baud, Switzerland, September 22, 1863, d. Nha Trang, Vietnam, March 1, 1943] discover that diphtheria is not caused directly by a bacterium but by a toxin produced by the bacterium. *See also* 1884 MED.

James McKeen Cattell [b. Easton, Pennsylvania, May 25, 1860, d. Lancaster, Pennsylvania, January 20, 1944] is appointed professor of psychology at the University of Pennsylvania, the first psychology professorship at any school. *See also* 1879 MED; 1890 MED.

⌘ Physics

Heinrich Hertz produces and detects radio waves for the first time; radio waves will be called Hertzian waves until renamed by Marconi, who calls them radiotelegraphy waves. *See also* 1883 COMM; 1894 COMM.

The release of negative electricity as a result of shining ultraviolet light on zinc, discovered by Wilhelm Hallwach [b. Darmstadt, Germany, July 9, 1859, d. Dresden, June 20, 1922], is the first confirmation of the photoemissive effect discovered by Heinrich Hertz. *See also* 1887 PHY; 1899 PHY.

I Tools

Charles Vernon Boys [b. Wing, Rutland, England, March 15, 1855, d. Andover, England, March 30, 1944] develops a very sensitive radiometer consisting of a thermocouple that becomes part of a string galvanometer. *See also* 1878 TOOL.

↗ Transportation

In Ireland, faced with unusually bumpy roads, John Boyd Dunlop [b. Ayrshire, Scotland, February 5, 1840, d. Dublin, October 23, 1921] re-invents air-filled rubber tires and establishes a company to manufacture them. *See also* 1845 TRAN.

Frank Sprague operates the first commercial American tramway on a 17-mile line in Richmond, Virginia. *See also* 1880 TRAN.

1889

★ Astronomy

Hermann Vogel discovers spectroscopic binaries, stars for which the light is shifted both to the red and the violet, indicating that there are two stars revolving about each other. The same discovery is made at Harvard Observatory about this time by Edward Pickering. *See also* 1892 AST.

▷ Chemistry

Vladimir Markovnikov constructs molecules that have carbon rings with seven atoms. *See also* 1882 CHEM.

German physicist Otto Lehmann [b. 1855, d. 1922] discovers that one liquid phase of cholesteryl benzoate is optically anisotropic — that is, the refractive index is dif-

ferent for light passing through in one direction than it is for light passing through perpendicular to that direction. He suggests the name "liquid crystal." *See also* 1888 CHEM; 1958 MATR.

⌚ Communication

British inventor William Friese-Greene [b. Bristol, England, September 7, 1855, d. London, May 5, 1921] patents a camera that takes ten photographs per second on a paper roll film. Filmed scenes at Hyde Park Corner are probably the first cinematic pictures ever projected (Edison's Kinetoscope did not involve projection). *See also* 1888 COMM.

George Eastman produces a celluloid version of roll film that is much simpler to work with than his previous paper roll film. This soon leads to a roll-film camera that is easy to use and opens the way for popular photography. *See also* 1887 COMM.

On November 23 Louis Glass installs a phonograph with four listening tubes in the Palais Royale Saloon in San Francisco, California. For a nickel, a customer can put an ear to the tube and hear a song. It is the ancestor of the jukebox. *See also* 1888 COMM; 1927 COMM.

As provided in the Treaty of the Meter, the International Bureau of Weights and Measures at Sèvres, France, establishes as prototypes the International Meter and International Kilogram, physical standards wrought of a special platinum-iridium alloy and kept under lock and key. Scientific and other measures are to be based on these pro-

totypes under rigidly decreed conditions of temperature, position on Earth's surface, and so forth. *See also* 1875 COMM; 1967 COMM.

💻 Computers

Léon Bollée [b. LeMans, France, 1870, d. 1913] builds the first mechanical calculator to include a built-in multiplication table. Previous calculators by Leibniz and Colmar used repeated addition for multiplication, while Schickard's calculator was based on Napier's bones. *See also* 1820 COMP; 1892 COMP.

🏗 Construction

Gustave Eiffel's tower in Paris, named after him, is completed. At 303 m (993 ft), it is the tallest free-standing structure built until that time. *See also* 1886 CONS.

The "wash-down" toilet, similar to the modern flush toilet with a ball float in the tank, is invented. *See also* 1886 CONS.

The Auditorium Building in Chicago, Illinois, is one of the first major buildings to use forced-air ventilation.

The Rand McNally Building in Chicago, Illinois, is the first to use steel in its framework throughout (with no cast iron). *See also* 1883 CONS; 1892 CONS.

❖ Materials

The artificial fiber rayon, a form of cellulose manufactured by the comte de Chardonnet, wins the Grand Prix at the Paris Exposition. *See also* 1884 MATR; 1890 MATR.

Frederick Augustus Abel [b. Woolwich, England, July 17, 1827, d. London, September 6, 1902] and James Dewar [b.

The skyscraper

A skyscraper described in a song from the musical *Oklahoma* as “Bout as high as a building ought to go” was in Kansas City, Missouri, and it was seven stories high. About the same time as the action in *Oklahoma*, another Midwestern city, Chicago, Illinois, boasted the earliest buildings recognized as skyscrapers today, which were two or three times as high.

The development of the skyscraper is often viewed as a consequence of the elevator. Elevators did permit buildings as tall as 10 to 16 stories, but lower floors were almost unusable. Concrete walls had to be 6 m (20 ft) thick to support the upper stories. The true key to the skyscraper was the steel frame that supported the walls and floors. Even so, the tallest office building to the end of the 19th century, the Park Row Building in New York City, was only 132 m (435 ft) high, half as tall as the Eiffel Tower, built around the same time. Also, early hydraulic elevators were only effective up to about 20 stories. Modern high-speed cable elevators, when introduced in 1900, greatly

facilitated the construction of what we would view today as skyscrapers.

William Le Baron Jenney in Chicago first used a mixture of cast iron and steel to support a tall office building, the Home Insurance Building. Soon he and other Chicago architects were using all-steel frames. What they mounted on the frames, however, was often a tall version of a Classic Revival building. Louis Sullivan, the Chicago architect who designed the first spare, modern looking buildings and who is best known today, was not a success during most of his career. His turn-of-the-century buildings that showed clearly the influence of the steel frameworks in vertical and horizontal lines were not acclaimed at the time, and Sullivan died in poverty in 1924 after years with no work. His influence lived on, however, as a result of his teaching.

In the 20th century, the largest number of tall skyscrapers were built in New York City, but Chicago also had its share of famous skyscrapers. Today Chicago still has the tallest building in the United States, the Sears Tower. Today, however, the tallest skyscraper in the world is the Taipei Financial Center in Taiwan, at 508 m (1667 ft); it was completed in 2003.

Kincardine, Scotland, September 20, 1842, d. London, March 27, 1923] invented cordite, smokeless gunpowder that is similar to Nobel's invention called ballistite. See also 1887 MATR.

U.S. chemist Francis Despard Dodge develops the alcohol citronellol with a rose or geranium odor and citronellal with various flower odors. These chemicals advance the artificial perfume industry. See also 1884 MATR.

Reinforced concrete is used in building a bridge. See also 1867 MATR; 1892 MATR.

The Pittsburgh Reduction Company introduces the first aluminum kitchen utensils. See also 1887 MATR.

Σ Mathematics

Arithmetices principia nova methodo exposita (“principles of arithmetic described by a new method”), a pamphlet in Latin by Giuseppe Peano,

Giuseppe Peano

[b. Piedmont (Italy), August 27, 1858, d. Turin, Italy, April 20, 1932]

Peano investigated the boundary between geometry and algebra. He created the Peano curve, which has continuity and yet no direction (that is, no tangent) at any point. Furthermore, the curve completely covers a given two-dimensional region. Peano also invented a useful symbolic logic and created the most accepted axiomatic system for the natural numbers.

includes his axioms for the establishment of the system of natural numbers and introduces much of the notation used for set theory and logic, including the common signs for contains, union, and intersection. See also 1858 MATH.

Giuseppe Peano's *I principii di geometria, logicamente expositi* (“the principles of geometry, logically explained”) translates the reformed Euclidean geometry of Moritz Pasch into symbolic logic, making it virtually impossible to understand. See also 1881 MATH.

Francis Galton's *Natural Inheritance*, reporting on his researches in genetics, includes the concept of the correlation coefficient and the

formula for the standard error.

♥ Medicine & health

Japanese bacteriologist Shibusaburo Kitasato isolates the tetanus bacillus.

French physiologist Charles-Edouard Brown-Séquard [b. April 8, 1817, d. April 1, 1894], considered a founder of endocrinology, injects himself during old age with hormones from testicles in hopes of experiencing a return of vigor. See also 1885 MED.

Oskar Minkowski [b. Aleksotas, Russia, January 13, 1858, d. Mecklenburg, Germany, July 18, 1931] and Baron Joseph von Mering [b. Cologne, Germany, February

28, 1849, d. Halle, Germany, January 5, 1908] attempt to find out if the pancreas has a function essential to life by removing the gland from dogs. Noticing that flies are attracted to the urine of their experimental dogs, they discover that the pancreas supplies a hormone essential to glucose metabolism (insulin). See also 1869 MED.

Baked porcelain inlays for lost teeth are introduced. See also 1890 MED.

An air lock, called a hospital lock, is introduced to eliminate caisson disease (nicknamed the bends) as part of an abortive attempt to build a tunnel under the Hudson River at New York City. By

providing a place for slow decompression for workers from the pressurized, under-water caissons, the hospital lock completely eliminates the disease, which previously had affected as many as one worker in four. *See also* 1779 CONS; 1907 MED.

✈ Transportation

Otto Lilienthal publishes *Der Vogelflug als Grundlage der Fliegekunst* ("bird flight as a basis for aviation"), which becomes an influential book for early aviation pioneers. *See also* 1877 TRAN; 1895 TRAN.

Ferdinand de Lesseps abandons the Panama Canal project when the first French company formed to build the canal goes bankrupt and loses the money of thousands of investors. A second French company is formed five years later, but it too fails. *See also* 1880 TRAN; 1894 TRAN.

1890

▲ Archaeology

Flinders Petrie compares pottery styles found in Egypt, in Greece by Schliemann, and in Palestine in his own investigation at Tell el Hesi, using Egyptian chronology to date the Greek Bronze Age and levels of civilization at Tell el Hesi. *See also* 1894 ARCH.

★ Astronomy

Edison makes unsuccessful attempts to detect radio waves from the Sun. *See also* 1931 AST.

Edward Pickering and Williamina Fleming [b. Dundee, Scotland, May 15, 1857, d. Boston, May 21, 1911] introduce a stellar classification system based on an alpha-



Baron Shibasaburo Kitasato

[b. Kumamoto, Japan, December 20, 1856, d. Nakanojo, Japan, June 13, 1931]

In 1889, while working with Robert Koch in Berlin, Germany, Kitasato became the first person to grow a pure culture of *Clostridium tetani*, the bacillus that causes tetanus. The following year he and Emil von Behring showed that animals injected with dilute tetanus toxin develop antitoxins that protect them against the disease. In 1894, after returning to Japan, Kitasato discovered *Yersinia pestis*, the bacillus that causes bubonic plague, also discovered independently by Alexandre Yersin.

betic system for spectral classes (known as Harvard Classification, it will become famous as the basis for the Draper Catalog). *See also* 1918 AST.

☛ Communication

A heliograph system is used by the U.S. army to send signals from mountaintop to mountaintop over a distance of 350 km (215 mi). *See also* 1854 COMM.

Edouard Branley [b. Amiens, France, October 23, 1844, d. Paris, March 24, 1940] invents the coherer, a small glass tube filled with iron filings. Normally the resistance of the iron filings is great, but in the presence of electromagnetic radiation the resistance becomes very small. Thus the device becomes the workhorse of early radio. *See also* 1894 COMM.

▀ Computers

Herman Hollerith [b. Buffalo, New York, February 29, 1860, d. Washington, DC, November 17, 1929] develops an electrically driven system based on punched cards that is used in counting the census. The American and Austrian censuses of 1890 and 1900 and the Russian census of 1895 are carried out on Hol-

lerith systems. *See also* 1805 TOOL; 1896 COMP.

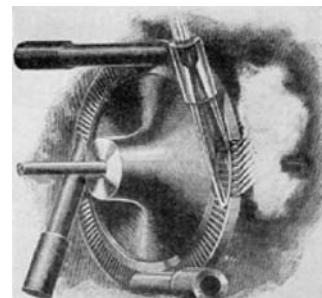
▼ Energy

Herbert Akroyd Stuart [b. Yorkshire, England, January 2, 1864, d. February 19, 1927] designs an internal combustion engine functioning at low pressure that uses kerosene as a fuel and that relies on the heat of the wall of the cylinder to vaporize the fuel and to ignite the air-fuel mixture. This is another important predecessor of the diesel engine. *See also* 1885 ENER; 1893 ENER.

Carl Gustav de Laval builds a steam turbine consisting of a single disk rotating at 30,000 revolutions per minute. *See also* 1888 ENER.

The first hydroelectric plant to produce alternating instead of direct current electricity is built on the Willamette River near Oregon City, Oregon. *See also* 1882 ENER; 1894 ENER.

William Kemmler on August 6 becomes the first person to be executed in the electric chair, a device developed by Harold P. Brown and E.A. Kenneally and that uses alternating current. Edison had arranged for prisons to have alternating current for the electric chair as an element in his fight to have



LAVAL'S STEAM TURBINE In the Laval steam turbine, a single turbine is powered by steam issuing from trumpet-shaped nozzle designed so that the flow strikes the many blades of the rotating wheel at great speed. Although highly efficient, the speed of the turbine was far too great for any practical purpose, so it had to be geared down. Furthermore, if the maximum possible amount of steam was used, the steel of the turbine tended to break down from the centrifugal force.

direct current adopted for household use. *See also* 1887 ENER; 1893 ENER.

▀ Food & agriculture

The Carpenter Electric Heating Manufacturing Company in Saint Paul, Minnesota, begins selling electric ovens.

Sven Foyn introduces the factory ship for hunting and processing whales. *See also* 1864 TOOL.

The perfect engine: the turbine

Turbines are devices that spin in the presence of a moving fluid. The difference between water wheels or windmills and turbines is largely one of emphasis and degree. During the 18th and 19th centuries, much progress was made toward extracting the kinetic energy of flowing water by devising water turbines. Leonhard Euler, applying fluid mechanics, developed a water turbine as early as 1750. During the 18th century several engineers, such as Benoît Fourneyron, succeeded in building water turbines that by far outstripped conventional water wheels by giving the blades special shapes. The term "turbine" was coined by Fourneyron's professor Claude Burdin; he derived the term from *turbo*, a spinning object.

The most useful turbines for many purposes are those that can be propelled with energy from heat. A typical turbine based on heat is the steam turbine. The idea of a steam turbine is much older than the steam engine itself. Around 60 BCE the Alexandrian Greek Heron (a.k.a. Hero) used jets of steam to turn a kettle. In 1629 the Italian engineer Giovanni Branca depicted in his machine book *Le Machine* a steam turbine in which a jet of steam is directed at the vanes of the same sort of apparatus as a water wheel. No doubt others observed that escaping steam is like the rushing wind and could be used to push mills just as the wind powers windmills.

When practical steam engines were built at the start of the 18th century, however, they moved a cylinder back and forth (reciprocating motion) instead of pushing a wheel around, although they could be made to turn wheels with various ingenious mechanisms. Reciprocating steam engines were bulky, had slow rotation speeds, and wasted much energy in the machine itself to move the heavy pistons back and forth. When first used to drive electric generators, reciprocating steam engines proved difficult to maintain at a fixed rotation speed as the load on the generator changed.

Turbines are as simple as reciprocating engines are complex.

Because they have essentially only one moving part, they are sometimes called the perfect engines, almost directly turning heat into rotary motion.

The first to build a steam turbine was the British engineer Charles Algernon Parsons. In 1884 he completed a small turbine that rotated at 18,000 revolutions per minute and that delivered 10 horsepower. The Swedish engineer Carl Gustav de Laval, experimenting with steam turbines, achieved greater power and higher rotation rates. In 1890 he built a turbine consisting of a 30-cm (12-in.) disk with 200 blades mounted on a flexible axis. The steam was admitted to the blades by special nozzles (Laval nozzles) that accelerated the steam to very high velocities, thus transferring the energy of the steam in the form of kinetic energy to the blades.

The design of steam turbines developed into a science near the end of the 19th century. Better materials allowed the construction of turbine blades that are resistant to corrosion. Charles Curtis developed the multistage turbine in which the blades and disks become progressively larger when the steam expands. Parsons developed in 1894 the ship turbine engine. The slow-revolving turbine consisted of several sections of increasing diameter. High-pressure steam is admitted to the turbine and pressure differences in each section drive the turbine blades. The first ship to be equipped with such a steam turbine, the *Turbinia*, immediately established a speed record with 31 knots (57.5 km or 35.7 mi per hour). During the early years of the 20th century, most reciprocating steam engines were replaced by steam turbines (or by diesels). Steam turbines can deliver much more power than reciprocating engines and need less maintenance. Steam turbines also supplanted marine steam engines on ships.

A similar evolution took place for large internal combustion engines, mainly driven by the need for lightweight and powerful airplane engines. Most large modern airplanes are now powered by either turboprop or turbojet engines. These turbines are spun by the expansion of jet fuel instead of by the expansion of water into steam.

Stephen M. Babcock [b. Bridgewater, New York, October 22, 1843, d. July 2, 1931] develops a test to measure the fat content of milk. *See also* 1879 FOOD.

❖ Materials

Louis-Henri Despeissis patents a method for making an artificial cellulose fiber that begins with the cellulose dissolved in a solution of copper ammonium, a method that was probably developed first

by M.E. Schweitzer in 1857 and perhaps was known even earlier than that. Despeissis's patent leads to commercial production of rayon by a similar process starting in 1898. *See also* 1889 MATR; 1892 MATR.

Σ Mathematics

Giuseppe Peano discovers a curve that, while one-dimensional and continuous, passes through every point in the interior of a square. *See also* 1872 MATH.

English physicist and electrical engineer Oliver Heaviside [b. London, May 18, 1850, d. Torquay, England, February 3, 1925] invents a form of operational calculus called the Heaviside calculus that uses several kinds of transformations to solve differential equations.

♥ Medicine & health

Emil von Behring develops a vaccine against tetanus and diphtheria and introduces the concepts of passive immu-

nization and antitoxins. *See also* 1885 MED.

The Principles of Psychology by William James [b. New York, New York, January 11, 1842, d. Chocorua, New Hampshire, August 26, 1910] becomes an enormous success. It describes psychology as a natural science. *See also* 1888 MED.

Cocaine is used as a local anesthetic in dentistry. *See also* 1884 MED; 1905 MED.

Benzocaine is developed in Germany. It is a local anesthetic that is given the trade name Anesthesia. *See also* 1884 MED.

Paul Ehrlich standardizes the diphtheria antitoxin, establishing the field of immunology. *See also* 1891 MED.

The porcelain jacket crown to cover lost portions of teeth is introduced by C.H. Land. The dentist removes the enamel from the tooth and mounts a porcelain shell baked onto a platinum matrix over what is left of the tooth. *See also* 1889 MED.

About this time physicians in Australia discover that children are being poisoned by ingesting old paint that has turned to powder. *See also* 1768 MED; 1917 MED.

Surgeon William Halsted [b. New York, September 23, 1852, d. Baltimore, Maryland, September 7, 1922] introduces the practice of wearing sterilized rubber gloves during surgery at Johns Hopkins Hospital in Baltimore. *See also* 1886 MED.

★ Physics

Johannes Rydberg [b. Halmstad, Sweden, November 8, 1854, d. Lund, Sweden, December 28, 1919] develops an empirical equation to describe the position of lines in the spectrum that is a generalized version of the better known Balmer equation. However, Rydberg discovers his equation without knowing of Balmer's work. *See also* 1885 PHY; 1913 PHY.

Sir James Alfred Ewing [b. Dundee, Scotland, March 27, 1855, d. Cambridge, England, January 7, 1935] discovers the



Emil von Behring

[b. Deutsch-Eylau, Germany, March 3, 1854, d. Marburg, Germany, March 31, 1917]

In 1901 Behring, a founder of the field of immunology, was awarded the first Nobel Prize in physiology or medicine for his work with diphtheria. He demonstrated that injecting dead or weakened diphtheria bacteria into an animal causes the animal's blood to produce a chemical — which he called an antitoxin — that neutralizes diphtheria toxin, providing immunity against the disease. Together with Shibasaburo Kitasato, Behring similarly showed that an animal's blood produces tetanus antitoxin when exposed to tetanus bacteria.

phenomenon of hysteresis in magnetic materials. This is the failure or lag of a ferromagnet to return to its original state when the cause of the magnetization is no longer present — although the magnetism can be removed by an opposite field to the initial one.

Hysteresis is the basis of magnetic memories used in tape recordings and computer disk drives. *See also* 1891 ENER.

Hendrik Antoon Lorentz [b. Arnhem, Netherlands, July 18, 1853, d. Haarlem, Netherlands, February 4, 1928] proposes that atoms may consist of charged particles that produce visible light by oscillating, essentially a correct idea although the actual situation is more complicated than Lorentz envisioned.

Roland, Baron von Eötvös [b. Budapest, Hungary, July 27, 1848, d. Budapest, April 8, 1919] conducts experiments in relating the gravitational and inertial masses of various substances. He shows that the two ways of calculating mass give the same results. This equivalence becomes one of the foundations of the general theory of relativity. *See also* 1915 PHY.

At Manchester University, Sir Arthur Schuster [b. Frankfurt, Germany, 1851, d. 1934] calculates the ratio of charge to

mass of the particles making up cathode rays by measuring the magnetic deflection of cathode rays. These particles are now known as electrons, but they were not recognized as such at the time. *See also* 1897 PHY.

I Tools

James Northrop develops an improved automatic weaving machine. The Northrop, patented by the American Draper Corporation, allows one weaver to tend to 16 looms at once. *See also* 1775 TOOL; 1920 TOOL.

Albert Charles Pain [b. 1856, d. 1929] patents a system of forced lubrication in machines based on oil conducted to joints and bearings through small canals. The system is now universally used in all kinds of machines. *See also* 1865 MATR.

→ Transportation

The *Eole* of Clément Ader [b. Muret, France, April 2, 1841, d. Muret, 1923] is the first full-size aircraft to leave the ground under its own power. Driven by a 15-kW (20-hp) steam engine, it flies over a distance of about 60 m (200 ft) carrying its inventor as pilot, although not very high off the ground at any time. Ader never has control of the

craft and it crashes on landing, which is why the invention of the airplane is seldom credited to him outside France. *See also* 1877 TRAN; 1897 TRAN.

The Forth railway bridge over the Firth of Forth in Scotland, designed by John Fowler [b. Sheffield, England, July 15, 1817, d. Bournemouth, England, November 20, 1898], is built using over 50,000 tons of steel, the first use of steel in a large and important structure. The amount of painting it takes to keep it from rusting will become a stock joke in Britain. The bridge is still in use. *See also* 1779 CONS.

1891

▲ Archaeology

On May 28 peat cutters working near Gundestrup in Northern Jutland (continental Denmark) find a large decorated silver bowl 70 cm (27 in.) in diameter, now known as the Gundestrup. The bowl, of mysterious origin, was probably hidden in a swamp about 100 BCE. A man with antlers and elephants are among the figures depicted on the bowl. *See also* 150 BCE MATR.

★ Astronomy

Maximilian Wolf [b. Heidelberg, Germany, June 21, 1863,

d. Heidelberg, October 3, 1932] makes the first discovery of an asteroid from photographs, finding the asteroid now called 323 Brucia. Wolf will proceed to use the photographic method to discover about 500 more asteroids, about a third of all asteroids known.

George Ellery Hale [b. Chicago, Illinois, June 29, 1868, d. Pasadena, California, February 21, 1938] invents the spectroheliograph, an instrument that allows making a photograph of the Sun in the light of a single spectral line. *See also* 1858 AST.

Seth Carlo Chandler [b. Boston, September 16, 1846, d. Wellesley Hills, Massachusetts, December 31, 1913] discovers the "Chandler" period, an oscillation of Earth's polar axis with a period of 14 months. *See also* 150 BCE AST.

Biology

Karl von Voit shows that various ingested sugars are converted to glycogen by the body for storage until needed. *See also* 1857 MED.

Heinrich Wilhelm Gottfried Waldeyer-Hartz is the first to note that the nervous system is built from separate cells and that the nerve cells do not actually touch each other. He coins the word *neuron* for nerve cell and his ideas are termed the neuron theory of the nervous system. *See also* 1852 BIO.

Eduard Strasburger establishes that physical forces, such as capillary action and osmosis, cause liquids to rise in plant stems — the cause is not some action of plants similar to the pumps that maintain blood

flow in vertebrates. *See also* 1826 CHEM.

Chemistry

German-Swiss chemist Alfred Werner [b. Mulhouse, France, December 12, 1866, d. Zurich, Switzerland, November 15, 1919] in his sleep develops the first inkling of his theory of secondary valence, a new way of explaining chemical structures beyond ionic and covalent bonds. *See also* 1852 CHEM; 1913 CHEM.

Communication

Gabriel Jonas Lippmann [b. Hollerich, Luxembourg, August 16, 1845, d. Atlantic Ocean, July 13, 1921] presents a paper to the Academy of Science in which he describes his color photography method that uses a thick emulsion over a mercury surface (used as a reflector) that captures the incident waves of light. The method is not very practical as the colors can only be seen at right angles. *See also* 1810 COMM; 1908 COMM.

Edison develops a system of taking motion pictures on the recently developed celluloid film of George Eastman. The strip of film is to be viewed through a magnifying glass as the film is wound from one reel to another inside a box. His patent application of August 24 (intended to replace his description of the cylinder device filed with the Patent Office in 1888) fails to suggest projecting the images. *See also* 1881 COMM; 1895 COMM.

Undertaker Almon Brown Strowger [b. Penfield, New York, 1839, d. St. Petersburg, Florida, May 26, 1902] invents the first practical telephone switching system in which the

caller determines who the receiver will be without the aid of a human operator. According to legend, Strowger is driven to this invention when the switchboard-operating wife of his chief rival begins to misdirect calls for Strowger to his chief business rival. Strowger's invention leads to the dial telephone. *See also* 1876 COMM.

Construction

In May Carnegie Hall in New York City, the first U.S. auditorium designed for musical performance (by architect William Burnet Tuthill [b. New York, February 11 1855, d. August 25, 1929]), opens, with 2247 seats and 65 boxes. Pyotr Illich Tchaikovsky conducts the opening program. *See also* 1895 CONS.

Earth science

The U.S. Weather Bureau leaves the military to become a separate department with Cleveland Abbe as the meteorologist in charge. *See also* 1871 EAR.

Energy

The first long-distance high-voltage line for carrying electricity is completed between Lauffen and Frankfurt. Its voltage is 8000 V and it bridges a distance of 177 km (120 mi). *See also* 1882 ENER. Clarence M. Kemp of Baltimore, Maryland, patents the first commercial solar water heater. *See also* 1882 ENER; 1977 ENER.

Nikola Tesla invents the Tesla coil, which produces high-voltage electricity at high frequencies. *See also* 1882 ENER.

German-American electrical

engineer Charles Proteus (Karl August) Steinmetz [b. Breslau (Wrocław, Poland), April 9, 1865, d. Schenectady, New York, October 26, 1923] announces his law of hysteresis, the loss of energy caused when magnetic action is converted to heat. Steinmetz's law enables the calculation of the loss mathematically. *See also* 1890 PHY; 1893 ENER.

The International Electrical Exhibition is held in Frankfurt.

Materials

Edward Goodrich Acheson [b. Washington, Pennsylvania, March 9, 1856, d. New York, July 6, 1931], while trying to make artificial diamonds, accidentally discovers a process for making carborundum (silicon carbide), a material almost as hard as diamond. *See also* 1929 MATR.

German-American chemist Herman Frasch [b. Württemberg, Germany, December 25, 1851, d. Paris, May 1, 1914] develops a method for removing sulfur from deep wells by melting the sulfur with superheated water.

Medicine & health

George Redmayne Murray [b. Newcastle, England, June 20, 1865, d. Mobberley, England, September 21, 1939] treats myxedema (the common form of hypothyroidism) with a hormone extracted from the thyroid gland. *See also* 1818 MED.

Paul Ehrlich uses methylene blue for treating malaria. *See also* 1666 MED.

An antitoxin for diphtheria is tested for the first time on humans. *See also* 1890 MED; 1901 MED.

Gottlieb Burckhardt, director of a Swiss mental asylum, writes the first description of the use of prefrontal lobotomy to cure mental illness. *See also* 1935 MED.

I Tools

John Wesley Hyatt, best known for his invention of celluloid, develops and markets the Hyatt roller bearing, still used in modern machines. *See also* 1496 TOOL.

André E. Blondel [b. Chaumont, France, August 28, 1863, d. Paris, November 15, 1938] invents the oscilloscope. *See also* 1893 TOOL.

The electric fan is invented.

Karl Elsener [b. Zug, Switzerland, October 9, 1860, d. December 26, 1918] devises the Swiss Army Knife.

→ Transportation

In a public lecture about space flight, eccentric German inventor Hermann Ganswindt proposes a spaceship that would be propelled by firing a cannon in the direction opposite to the one in which one wishes to travel. This is an awkward equivalent to rocket propulsion. *See also* 1881 TRAN.

1892

★ Astronomy

Edward Barnard is the first person to discover a comet in a photograph of the sky instead of by visual sighting. *See also* 1881 AST.

On September 9 Edward Barnard discovers a fifth moon of Jupiter, the first satellite of Jupiter found since Galileo. Amalthea, as the moon is named, is the

last planetary satellite to be discovered without the aid of photography or space probes.

Edward Barnard observes that a nova emits a cloud of gas when it brightens, the first clear evidence that novas are explosions on stars (explosions of stars are supernovas).

↗ Biology

Das Keimplasma (“germ plasma”) by German biologist August Weismann describes his theory that germ plasma is unchanged from generation to generation and that changes in the body do not affect it. He theorizes that germ plasma is in the chromosomes. *See also* 1888 BIO.



August Friedrich Leopold Weismann
[b. Frankfurt, Germany, January 17, 1834, d. Freiburg-im-Breisgau, Germany, November 5, 1914]

In a famous series of experiments in which he cut off the tails of mice for 22 generations, Weismann disproved the theory that acquired characteristics could be inherited. A strong proponent of Darwinian evolution, Weismann also proposed the germ plasma theory. This theory suggested that while the body, which Weismann called somatoplasm, lives for only one generation, hereditary material, which he called germ plasma, is immortal, passed from generation to generation without change.

▷ Chemistry

Sir William Ramsay [b. Glasgow, Scotland, October 2, 1852, d. High Wycombe, England, July 23, 1916] announces on August 13 the discovery of argon (Ar), based on a suggestion from Lord Rayleigh, who had in 1882 discovered that nitrogen from air seemed to have a different atomic weight from nitrogen prepared in other ways. *See also* 1785 CHEM; 1904 PHY.

↳ Communication

Thomas Oliver [b. Canada, August 1, 1852, d. February 9, 1909] in Ohio patents and produces the first practical typewriter for which the operator is able to see the words as they are typed. *See also* 1872 COMM.

▀ Computers

The “Millionaire,” the first efficient four-function calculator, which Swiss inventor Otto Stieger bases on the calculator invented by Léon Bollée, appears on the market and remains successful until 1935. *See also* 1889 COMP.

William Burroughs introduces an adding-subtracting machine with printer. *See also* 1888 COMP.

▀ Construction

The 21-story Masonic Building in Chicago, Illinois, uses light, thin screens between columns and beams in a modified form of curtain-wall construction. *See also* 1851 CONS; 1918 CONS.

↗ Energy

Henri Moissan describes the use of acetylene gas for lighting. About the same time Thomas L. Willson also

describes the use of acetylene to produce a brilliant white light. *See also* 1862 MATR; 1901 ENER.

Leon Arons [b. Berlin, 1860, d. 1919] designs the first full-fledged mercury-vapor lamp, but does not manufacture it for general use. *See also* 1901 ENER.

▀ Food & agriculture

John Froelich [b. Giard, Iowa, November 24, 1849, d. 1933], an Iowa farm machinery dealer, builds the first mechanically successful internal combustion engine tractor. *See also* 1837 FOOD; 1901 FOOD.

◊ Materials

An artificial fiber made from cellulose zanthate by the team of Charles Frederick Cross [b. Brentford, England, December 11 1855, d. Hove, England, April 15, 1935], Edward J. Bevan [b. Birkenhead, England, 1856, d. 1921], and Clayton Beadle using their “viscose” process, often called viscose rayon, is the foundation of much of the artificial fiber industry that follows. *See also* 1890 MATR.

French engineer François Hennebique [b. 1843, d. 1921] improves reinforced concrete by introducing steel bars laid out into three rectangular frames at right angles to each other. The enclosed steel frame makes the material more resistant to bending, traction, and shearing forces. *See also* 1877 MATR.

On May 2 Thomas L. Willson [b. Princeton, Ontario, 1860, d. New York City, 1915], in conjunction with chemistry professor F. P. Venable and William Rand Kenan, Jr., while seeking a way to pro-

duce aluminum cheaply, accidentally produces both acetylene and calcium carbide, both in quantity and at low production costs. *See also* 1862 MATR.

Σ Mathematics

Georg Cantor describes his “diagonal method,” which he uses to prove that the infinity of real numbers (all numbers that can be represented by infinite decimals) is different from and greater than the infinity of natural numbers (1, 2, 3 . . .). *See also* 1911 MATH.

♥ Medicine & health

Paul Ehrlich distinguishes between active and passive immunity. *See also* 1890 MED.

Camillo Golgi shows that in intermittent malaria, the malaria parasites develop in the blood while in pernicious malaria, the parasites develop in the organs and brain. *See also* 1885 MED.

Russian-British bacteriologist Waldemar Mordecai Wolfe Haffkine [b. Odessa (Ukraine), March 15, 1860, d. Lausanne, Switzerland, October 25, 1930] develops an attenuated strain of the cholera bacteria, which he tests on himself. The next year he uses it on 45,000 people in India, where it reduces the death rate by 70 percent among those inoculated. *See also* 1883 MED.

Max Joseph von Pettenkofer [b. Lichtenheim, Germany, December 3, 1818, d. near Munich, February 10, 1901] miraculously fails to get sick after swallowing cholera bacteria in an effort to disprove the germ theory of disease.

Pathologist Theobald Smith

[b. Albany, New York, July 31, 1859, d. New York, New York, December 10, 1934] discovers that Texas cattle fever is spread by ticks. This is the first known arthropod vector for disease and paves the way for the discovery of how such diseases as malaria, typhus, and Lyme disease are spread. *See also* 1897 MED.

Russian biologist Dmitri Ivanovsky [b. Gdov, Russia, November 9, 1864, d. Soviet Union (Russia), June 20, 1920] shows that tobacco mosaic disease can be passed through a porcelain filter fine enough to remove all bacteria. This establishes that something smaller than bacteria (perhaps even a liquid) causes the disease. The causative agent is labeled a filterable virus, or simply a virus. *See also* 1894 PHY; 1898 BIO.

Robert Koch introduces filtration of water for controlling a cholera epidemic in Hamburg, Germany. *See also* 1866 MED.

⌘ Physics

The fine structure in the spectral lines of hydrogen is detected for the first time. This is a splitting of the lines into multiples at nearly the same location in the spectrum. Analysis of the cause for this splitting will lead to development of theories of particle spin and its relation to the orbital motion of the hydrogen electron.

In response to the Michelson-Morley experiment, George Fitzgerald formulates the theory that objects that move at velocities close to that of light undergo a contraction, now known as the Lorentz-Fitzgerald contraction as the same

conclusion will be reached independently by Hendrik Lorenz in 1895. *See also* 1887 PHY; 1895 PHY.

Heinrich Hertz, who has concluded (incorrectly) that cathode rays must be some form of wave, shows that the rays can penetrate thin foils of metal, which he takes to support the wave hypothesis. *See also* 1894 PHY.

Hungarian-German physicist Philipp Eduard Anton von Lenard [b. Pressburg, Austria-Hungary (Bratislava, Slovakia), June 7, 1862, d. Messelhausen, Germany, May 20, 1947] develops a cathode-ray tube with a thin aluminum window that permits the rays to escape, allowing the rays to be studied in open air. *See also* 1905 PHY.

I Tools

Henri Moissan introduces an improved electrical arc furnace for metallurgy.

James Dewar invents the Dewar flask or Dewar bottle, the first form of thermos bottle. The Dewar bottle (and the thermos bottle) is a double-walled flask with a vacuum between the walls. The walls are silvered to reflect heat radiation and the vacuum prevents heat passing through by conduction or convection — thus, cold matter in the flask stays cold for longer periods of time, which was Dewar’s goal, and hot matter stays hot as well. *See also* 1865 TOOL; 1898 MATR.

↗ Transportation

Konstantin Tsiolkovsky starts construction of a number of wind tunnels for measuring air friction on moving vehicles.

1893

▲ Archaeology

In southern Utah Richard Wetherill discovers mummies of the “Basket Makers,” an American Indian culture that preceded the cliff dwellers who built Mesa Verde. *See also* 1888 ARCH.

★ Astronomy

Edward Walter Maunder [b. London, April 12, 1851, d. London, March 21, 1928] discovers in the historical records of sunspots the “Maunder minimum,” a period from 1645 to 1715 when almost no sunspots were observed. Tree rings and other evidence suggest that this period was the middle of the Little Ice Age, when global temperatures were low.

↗ Biology

Santiago Ramón y Cajal [b. Petilla de Aragón, Spain, May 1, 1852, d. Madrid, October 18, 1934] proposes that learning occurs as a result of increased connections between neurons. He develops detailed drawings of stained samples of brain tissue that support this point of view. These will be published in 1894 through 1904 as *Textura del Sistema Nervioso del Hombre y los Vertebrados* (“structure of the nervous system in men and vertebrates”). *See also* 1906 BIO.

↳ Communication

Louis Ducos du Hauron invents a method of producing three-dimensional-appearing images based on using a stereoscope and images that are viewed through filters with a different

color for each eye. *See also* 1847 COMM; 1903 COMM.

Belgian-American chemist Leo H. Baekeland [b. Ghent, Belgium, November 14, 1863, d. Beacon, New York, February 23, 1944] introduces a photographic paper that is sensitive enough for printing by artificial light (Velox). It revolutionizes the process of making photographic prints. *See also* 1889 COMM.

Valdemar Poulsen [b. Copenhagen, Denmark, November 23, 1869, d. Copenhagen, July 1942] develops the first magnetic sound recorder, the telegraphon. The sound is recorded as magnetized regions on a steel wire that is wrapped around a cylinder. *See also* 1888 COMM.

► Energy

George Westinghouse, who bought the patents for alternating-current (a.c.) devices from Nikola Tesla, having outbid Edison because of the efficiency of a.c. over direct current (d.c.) for the contract to light the Chicago World's Fair (Columbian Exposition), scores a dramatic success with lighting and demonstrations of the a.c. system at the fair. Immediately after this, about 80 percent of new electrical networks use a.c., which is 100 percent today. *See also* 1887 ENER.

Charles Proteus Steinmetz develops the mathematical theory of alternating current in a simplified fashion that is clear to engineers. *See also* 1891 ENER.

Wilhelm Maybach develops the float-feed carburetor in which gasoline and air are mixed to form the explosive mixture entering the cylinder

of a gasoline motor. Maybach's carburetor is used for the four-stroke Daimler engine in 1897 and for most automobile motors thereafter. *See also* 1885 ENER.

Rudolf Diesel [b. Paris, March 18, 1858, d. English Channel, September 30, 1913] describes an internal combustion engine, first built the previous year, that will be named after him. The ignition of the gas mixture in the cylinder is obtained by heating during the compression cycle. *See also* 1890 ENER.

Edward Weston [b. Wolverhampton, England, May 9, 1850, d. Montclair, New Jersey, August 20, 1936] invents a standard voltage cell named after him.

◊ Materials

Henri Moissan announces that he has used heat and pressure to produce an artificial diamond. Studies show later that he did not have enough heat or pressure to produce a diamond and that the diamonds he exhibited may have been placed in his equipment as a hoax by unknown perpetrators. Moissan also describes the use of an electric furnace for smelting metals. *See also* 1879 MATR; 1907 MATR.

Edward Drummond Libbey [b. Chelsea, Massachusetts, April 17, 1854, d. November 13, 1925] produces fabric woven from glass fibers and silk. *See also* 1713 MATR.

Whitcomb L. Judson patents a "clasp locker or unlocker for shoes." After various changes and improvements over the next 30 years, the "clasp locker" evolves into the slide fas-

tener best known as the zipper. *See also* 1914 TOOL.

Σ Mathematics

The first volume of Gottlob Frege's *Grundgesetze der Arithmetik* ("fundamental laws of arithmetic") continues his efforts to derive arithmetic from logic, but his complex notation results in the book attracting little attention; volume two is published in 1903. *See also* 1884 MATH.

♥ Medicine & health

African-American surgeon Daniel Williams [b. Holidaysburg, Pennsylvania, January 18, 1858, d. Idlewild, Michigan, August 4, 1931] performs the first open-heart surgery on a patient injured by a knife wound. *See also* 1914 MED.

Physician Niels Ryberg Finsen [b. Faeroe Islands, Denmark, December 15, 1860, d. Copenhagen, September 24, 1904] claims that red light reduces the symptoms of smallpox. Although this idea will later be abandoned, Finsen goes on to establish that ultraviolet light kills bacteria and cures the skin disease *lupus vulgaris*.

German pharmacist Felix Hoffman [b. January 21, 1868, d. February 8, 1946], working for the Adolf von Bäyer firm in Elberfeld, Germany, synthesizes aspirin (acetyl salicylate). It is made by a variant of the method used earlier by Hermann Kolbe to produce salicylic acid, but aspirin is not as unfriendly to the stomach lining as salicylic acid is. Hoffman's motivation is to develop a treatment for his father's rheumatoid arthritis. In 1899 aspirin will be first used for arthritis, although it had been previously used for fever and pain reduction in other dis-

eases. Aspirin is still among the most effective treatments for arthritis although side effects, especially stomach bleeding, limit its use. *See also* 1859 CHEM.

⊗ Physics

Wilhelm Wien [b. Gaffken, East Prussia (Primorsk, Russia), January 13, 1864, d. Munich, Germany, August 30, 1928] discovers that the maximum wavelength emitted by a hot body varies inversely to its absolute temperature (Wien's displacement law) — that is, as a body becomes hotter, the light emitted has shorter wavelengths, going from red to blue. Wien's law, which contains a specific formula for peak wavelength, will become useful in establishing the temperature of stars.

I Tools

William Du Bois Duddell [b. England, 1872, d. November 4, 1917] improves the oscilloscope and gives it the design it has today. *See also* 1891 TOOL; 1893 COMM.

James J. Harvey patents Harvey's Pneumatic Dusting Machine, a sort of vacuum cleaner operated by two persons, one of them working a bellows and the other pushing the dust collector from place to place.

→ Transportation

A project under consideration from time to time for about 2500 years is finally completed when a shipping canal is dug across the Isthmus of Corinth. *See also* 60 CE TRAN.

Australian Lawrence Hargrave [b. Greenwich, England, January 29, 1850, d. July 1915] invents the box kite.

1894

► Anthropology

Marie Eugène François Thomas Dubois [b. Eijsden, Netherlands, January 28, 1858, d. Halen, Belgium, December 16, 1940] publishes his discovery of fossil remains of a precursor of *Homo sapiens* in Java. Called *Pithecanthropus erectus* by Dubois, the species is now known as *Homo erectus*. See also 1868 ANTH; 1895 ANTH.

▲ Archaeology

Flinders Petrie begins excavation of the cemetery of Nagada in Egypt, the first evidence of an Egyptian civilization from before the first known dynasty of Pharaohs. See also 1890 ARCH; 1922 ARCH.

★ Astronomy

Percival Lowell [b. Boston, Massachusetts, March 13, 1855, d. Flagstaff, Arizona, November 12, 1916] founds his observatory at Flagstaff, Arizona, and starts searching for a hypothetical ninth planet. See also 1846 AST; 1930 AST.

♫ Biology

William Bateson publishes *Material for the Study of Variation*. It includes his version of punctuated equilibrium, called the theory of discontinuity, to explain the process of evolution. According to this theory, species evolve in a series of discontinuous jumps. See also 1858 BIO; 1972 BIO.

Eduard Adolf Strasburger shows that spore-bearing generations in nonflowering plants, such as ferns and moss, are diploid (with pairs of chromosomes), while the sexual generation has haploid egg and sperm cells (with only one chromosome of each type). See also 1875 BIO.

Max Rubner demonstrates that the amount of energy produced by food used by the body is the same as the energy produced if the food is burned (after urea, which the body does not consume in respiration, is removed). See also 1884 BIO.

◊ Chemistry

Swiss-American chemist John Ulric Nef [b. Herisau, Switzerland, June 14, 1862, d. Carmel, California, August, 1915] discovers what is now called the Nef reaction for the formation of aldehydes and ketones from nitroalkanes. Nef is also known for establishing that carbon can have a valence of two as well as its more common valence of four. See also 1857 CHEM.

☛ Communication

Electrical engineer Guglielmo Marconi builds his first radio equipment, a device that will ring a bell from 10 m (30 ft) away. See also 1888 PHY; 1899 COMM.

Edouard Branley detects with his coherer radio waves produced by a spark generator at a distance of 30 m (100 ft). The receiving circuit consists of a battery, a coherer, and a galvanometer. The galvanometer indicates a current as soon as the spark generator starts working. See also 1888 PHY; 1901 COMM.

Oliver Lodge demonstrates the transmission of radio signals over a distance of 60 m (180 ft) at the annual meeting of the British Association for the Advancement of Science. See also 1888 PHY; 1899 COMM.

Eugene Porzolt invents a photographic method for the composition of type based on letters projected on a sensitive plate. The system, now known as photocomposition, becomes commercially available 50 years later. See also 1884 COMM.

⊕ Earth science

James Geikie publishes the third edition of *The Great Ice Age* (first edition, 1874).



Marchese Guglielmo Marconi

[b. Bologna, Italy, April 25, 1874, d. Rome, July 20, 1937]

In 1894 Marconi read that Heinrich Hertz, by inducing an electric spark to jump across a gap, had produced invisible waves that travel through space. Marconi realized that the waves might be used to send wireless messages similar to the dot-and-dash messages sent by telegraphs. He began experimenting and within a year was sending messages over distances of more than a mile (1.6 km). Widespread use of radio was assured on December 12, 1901, when assistants in England sent the first transatlantic signals to Marconi in Newfoundland, a distance of some 4800 km (3,000 miles).

William Bateson

[b. Whitby, Yorkshire, England, 1861, d. Merton, Surrey, England, February 8, 1926]

After graduating from Cambridge University, Bateson did research in the United States on the wormlike marine animal *Balanoglossus*, then classified as an echinoderm. Bateson recognized that the animal had a notochord, correctly identified it as a chordate, and hypothesized that chordates may have evolved from echinoderms (today a widely accepted theory). Following his return to Cambridge in 1885, Bateson theorized that variations within a species are not related to environmental conditions. The discovery of Mendel's work in 1900 supported Bateson's theory. Bateson also showed that, unlike the characteristics studied by Mendel, some characteristics are governed by more than one gene. He coined the name "genetics" for the new science of heredity.

Geologist Thomas Chrowder Chamberlin [b. Mattoon, Illinois, September 25, 1843, d. Chicago, Illinois, November 15, 1928] is among the first to realize that there were several ice ages, not just one. Thomas Chamberlin presents his evidence of multiple ice ages in North America in this edition of Geikie's work. See also 1874 EAR; 1896 EAR.

☛ Energy

Carbon filaments based on squirted cellulose are introduced and become the standard filaments for Edison and Swan incandescent lamps. See also 1879 ENER; 1904 ENER.

The development of radio

It is often argued that science and technology develop independently and that new technologies only rarely are directly derived from scientific developments. There are enough examples of recent technological developments, such as the transistor or the laser, to contradict this. The development of radio communications is an early example of the direct application of physics.

It was an international collaboration. The theoretical basis of radio waves was laid by British physicist James Clerk Maxwell, who gave a thorough mathematical description of electromagnetic waves in 1873. Maxwell showed that light is an electromagnetic wave, but that electromagnetic waves with a much longer wavelength than that of light — now known as radio waves — also exist. Ten years later Irish physicist George Francis Fitzgerald suggested the way in which such waves could be produced. German physicist Heinrich Hertz was the first to deliberately produce such waves, showing that they are reflected and refracted in the same way as light.

In 1887 Hertz started his experiments, creating radio waves by producing sparks with a high-voltage induction coil, a device not very different from the coil that delivers the high-voltage pulses to the spark plugs in an automobile engine. As "receiver" he used two small spheres attached to the ends of an open loop of wire. When he brought the loop in the beam of electromagnetic radiation produced by the spark generator, he observed small sparks that jumped between the two spheres.

The coherer, invented independently a half-dozen years later by British physicist Oliver Lodge and French scientist Edouard Branley, was a more sensitive detector for radio waves than the receiving loop of Hertz. It consisted of a small tube filled with iron filings connected to electric wires at each end. In the presence of an electromagnetic wave, the iron filings line up (as Lodge expressed it, become "coherent") and the coherer starts conducting electricity. Branley could detect radio waves produced by a spark generator up to a distance of 30 m (100 ft), and Lodge was able to double that feat.

Guglielmo Marconi is generally credited as the inventor of radio communication as such, although transmitters and receivers had been built before him by other experimentalists. In 1894, when reading about the electromagnetic waves discovered by Heinrich Hertz, Marconi realized that the waves could be used for the transmission of signals in the same way as electric wires.

Marconi started experimenting with radio waves with the help of the physicist Augusto Righi. Lacking formal training in physics, Marconi proceeded empirically. He used a transmitter consisting

of a high-voltage coil and a spark gap connected to an antenna circuit. The receiver consisted of a coil connected to a coherer, which conducts electricity when a radio signal is present. From the beginning Marconi concentrated on producing useful effects, such as ringing a bell from a distance. Marconi also went somewhat further than the physicists by experimenting with antennas, for which a physical theory was still nonexistent. By connecting an antenna and an earth conductor (ground) to the transmitter and receiver, Marconi was able to transmit radio signals over increasing distances. He experimented with different kinds of antennas and soon succeeded in transmitting signals over 2.4 km (1.5 mi).

Marconi tried first to interest the Italian government in his experiments. But the government showed no interest, so Marconi moved to England to continue his experiments there. In England he successfully applied for a patent for his system of radio transmission, and in 1897, with the help of wealthy relatives, he set up the Wireless Telegraph and Signal Company.

By trying different types of antennas and increasing the power of the transmitter, Marconi pushed signals to carry over much larger distances — reaching 240 km (150 mi) in 1900 and across the Atlantic Ocean in 1901.

The British army and navy became Marconi's first customers, buying systems developed by his company. By 1900 Marconi founded a subsidiary that leased radio communication systems, including radio operators, to ships and shore stations.

Mainly under the impetus of Marconi, radio communication systems developed quickly. The early transmitters were all of the spark-generator type, producing electromagnetic radiation in a pulselike manner. Such transmitters produced radiation in a wide spectrum, with the consequence that nearby transmitters easily interfered with each other. Although tuned circuits, introduced by Oliver Lodge and by Marconi, were an improvement, the greatest breakthrough in radio communication was the vacuum-tube oscillator. Such an oscillator could produce a continuous radio wave occupying only a narrow frequency range.

Canadian inventor Reginald Aubrey Fessenden was producing voice transmission as early as 1904 and soon was making experimental voice broadcasts that could be received all up and down the Atlantic coast of the United States. The introduction of the vacuum tube in 1913 also made possible a better way to modulate radio waves. Radio receivers using vacuum tubes were much more sensitive because the high-frequency signals as well as audio signals were amplified. Fessenden and other inventors, such as the American Edwin H. Armstrong, soon produced much more powerful transmitters and improved receivers based on vacuum tubes, although some early programs continued to use spark-generated signals until the early 1920s.

❖ Materials

Charles Cross and Edward Bevan develop a dye of the type called azo by chemists. It stays fast better than other azo dyes because it is chemically linked to the cellulose-based artificial fiber. This is the first fiber-reactive dye, but the process of dyeing with it is too complicated to use commercially. *See also* 1880 MATR; 1956 MATR.

In Greenland Robert Edwin Peary [b. Cresson, Pennsylvania, May 6, 1856, d. Washington, DC, February 20, 1920] notes that natives make tools from copper broken from a large meteorite. The remaining 37-ton copper meteorite is now in the American Museum of Natural History in New York. *See also* 8000 BCE MATR.

Artificial emery (aluminum oxide, considered a variety of corundum) is produced. *See also* 1891 MATR; 1898 MATR.

Σ Mathematics

(Félix Edouard Justin) Emile Borel [b. Aveyron, France, January 7, 1871, d. Paris, February 3, 1956] proves an important technical theory needed to put calculus on a firm foundation. The theorem, which concerns the ability to cover a set of points with a finite number of intervals, is correctly known as the Heine-Borel theorem since Eduard Heine also independently proved it. *See also* 1872 MATH.

Elie Joseph Cartan [b. Dolomieu, France, April 9, 1869, d. Paris, May 6, 1951] in his doctoral thesis classifies all finite groups that are known at this time. *See also* 1870 MATH; 1980 MATH.

♥ Medicine & health

Shibasaburo Kitasato and Alexandre Yersin independently discover the bubonic

plague bacterium. *See also* 1345 MED; 1898 MED.

⌘ Physics

J.J. Thomson announces that he has found that the velocity of cathode rays is much lower than that of light. *See also* 1892 PHY; 1897 PHY.

I Tools

Engineer Frederick Winslow Taylor [b. Philadelphia, Pennsylvania, March 20, 1856, d. Philadelphia, March 21, 1915] is among the first to make time-and-motion studies of workers with the idea of eliminating unneeded steps.

American Daniel M. Cooper invents the time clock.

✈ Transportation

A new French company charged with building the Panama Canal is formed, although the project is no longer backed by the French

government after the United States declares that such government backing would be against the Monroe Doctrine. *See also* 1889 TRAN; 1914 TRAN.

British Major Baden F.S. Baden-Powell [b. May 22, 1860, d. October 3, 1937] uses kites to lift human beings into the air. *See also* 1871 TRAN.

John Thornycroft and Sydney W. Barnaby discover strong vibrations from the propellers of the first British destroyer and find the cause of it: erosion caused by bubbles, known as cavitation. *See also* 1844 TRAN; 1920 ENER.

Charles Parsons invents the ship turbine engine. *See also* 1888 ENER.

The first electric automobiles appear on the market. The electric motor is powered by a rechargeable battery. *See also* 1881 ENER; 1900 ENER.



Rise of Modern Science and Technology: 1895 through 1945

Beginning just before the start of the 20th century a series of related developments in physics — the discovery of X rays, radioactivity, subatomic particles, relativity, and quantum theory — led to a profound revolution in how scientists view matter and energy. In turn, these developments affected to various degrees chemistry, astronomy, geology, biology, medicine, technology, and, ultimately, the fate of Earth, since they culminated with the first nuclear weapon, the atomic bomb, in 1945.

The growth of 20th-century science

Science during the 19th century was still the occupation of only a few persons. During the 20th century, however, the number of scientists became so large that it has almost become a cliché that more scientists lived in the 20th century than in all previous eras together. The nature of scientific research had profoundly changed as well; science became much more of a communal effort. Its progress was not only determined by the great discoveries of a talented few, such as Einstein, Bohr, and Rutherford, but also by the numerous small steps made by specialized researchers who did not have a famous formula or law named after them. Many scientific advances were also made by teams of researchers, each working on a small piece of a puzzle.

Many of the observations and discoveries made during the 19th century, such as the periodic table, Mendel's laws, and the negative result of Michelson's and Morley's experiment to measure the velocity of Earth against the

ether, were explained by new scientific theories that emerged early in the 20th century.

Much of the methodology worked out by the great scientists during the 19th century started to bear fruit in the 20th century. For example, the microscopic staining techniques developed during the late 19th century led to the discovery of many new organisms that cause disease. The synthesis of new chemical compounds became a daily occurrence.

During the 19th century society was transformed through technology; many of the great inventions, from the cotton gin to the electric light, were produced by people with little interest in or knowledge of basic science. But in the 20th century, science itself started having an effect on society directly. For example, the time span between a discovery and its technical application became much shorter. The discovery of the electron resulted in the construction of electron tubes in less than 20 years, with the ensuing revolution in communications, including broadcasting and long-distance telephoning.

Around 1900 Germany played the leading role in science and technology. Since the middle of the 19th century, Germany had been the most successful in applying chemistry to industry; it became the leader in the production of dyestuffs and other chemical products. The development of the German pharmaceutical industry was a consequence of this industrial leadership. Germany lost its leading role in the sciences when Hitler came into power. Largely because of the influx of European scientists fleeing Hitler, the United States became the

leading country of science. Between 1932 and 1938, 8 of the 28 Nobel laureates in science were American, but these were native-born, not émigrés. After 1938, although the United States continued to be heavily represented among the Nobel laureates, many of the U.S. winners had lived in Germany longer than they had lived in America.

World War I showed that science could play an important role in the outcome of a war. In Germany, more than a hundred laboratories were involved in scientific research for the military. During the years after World War I, governments in the East and West started actively funding science, thus largely contributing to the enormous growth of science during the 20th century. Scientists played a major role during World War II, their work culminating in the development of nuclear weapons.

New philosophies

Science in the first half of the 20th century became highly successful in explaining the nature of matter, mechanisms of chemical reactions, fundamental processes of life, and the general structure of the universe. These successes of science started to exert a profound philosophical influence on the outlook of human beings, a phenomenon somewhat similar to the philosophical swing that occurred during the Enlightenment. The American philosophers C.S. Peirce and William James, founders of the philosophical school of pragmatism, held similar ideas to those of Ernst Mach. They believed that reality could be understood by experience alone. At the same time it became clear

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that science, especially mathematics, was also based on logical reasoning. The philosophical school termed New Realism combined the strictly empiricist views of James and Mach with Georg Hegel's idea that knowledge can be attained only from *a priori* concepts by logic (although Mach believed that science is not only based on empirical facts, but also on underlying principles). The scientific view became the only acceptable view of reality and in many cases the model for philosophical thinking.

Darwin's theory of evolution also had a major impact on philosophers, especially Herbert Spencer, Henri Bergson, and John Dewey. Natural selection, which is the basis of Darwin's theory of evolution, became a principle accepted in the social sciences and psychology. Spencer's ideas had become almost a philosophical system: Evolution and natural selection were not only the fundamental laws of the living world, but also of society, ideas that resulted in the laissez-faire political philosophies of the first decades of the 20th century.

Changes in mathematics and the development of psychology also had important philosophical implications.

Quantum reality

Another prominent scientific concept that changed the way philosophers think about the universe is quantum theory. Around the end of the 19th century, Newton's mechanics and Maxwell's electromagnetic theory failed in several areas. It became clear that one cannot trace all physical phenomena back to these sets of "laws." To resolve these issues, physicists developed quantum mechanics and abandoned several of the tenets of classical physics. Wolfgang Pauli and Werner Heisenberg introduced theories in which the visualization of phenomena (as was possible in classical physics) was eliminated.

Erwin Schrödinger developed an equivalent theory that was later interpreted in terms of waves of probability. In this theory, the electron could not be viewed as a point mass orbiting the nucleus, but as a wave train of probability showing where the electron might be. The idea that each particle could be associated with a wave came from Louis de Broglie; experiments soon showed that electrons could behave as waves when they pass through crystals and are diffracted.

In 1927 Heisenberg introduced one of the most fundamental principles of quantum mechanics: It is not possible to simultaneously observe the position and the momentum of a particle (such as the electron) with absolute accuracy. This principle is known as the principle of uncertainty, and Bohr incorporated it into his concept of complementarity: If you observe a system, you interact with it, disturbing it. Bohr elevated the concept of complementarity to a fundamental principle of the natural sciences; it includes the complementarity between the wave and the particle theory of light. Light can be viewed as a wave, for example, when it is diffracted passing through a narrow slit, or as a particle, when ejecting an electron from a metal surface in the photoelectric effect.

These changes affected the way scientists viewed reality in fundamental ways.

Energy wherever needed

Many inventions that mark the technological development of the 20th century were put in place during the last two decades of the 19th century: the telephone, electric generator, electric light, steam turbine, cheaper processes for making steel and aluminum, automatic machine tools, and, most important in its effect on society, the internal combustion engine.

One important consequence of these inventions was that technology did not remain confined to large enterprises only, as was true for most of the 19th century. Through most of the 19th century ordinary people came into very little contact with technology and lived the same way as during the earlier centuries. Around the end of the 19th century, mainly through the impetus of electricity, technology started to become an important part of everyday life in the industrialized world. First the electric light and the telephone entered the home. The widespread availability of electricity opened the way to a host of kitchen and other appliances. The vacuum cleaner and electric iron soon became common, followed during the 1920s and 1930s by the refrigerator and washing machine.

A second factor that contributed to the spread of technology was the enormous growth of the automobile industry. Automobile use spread the most quickly in the United States, where there were 2,500,000 registered motor vehicles in 1915. Automobile manufacture drove the economy of the United States and other developed countries, paving the way for sharp increases in materials manufacture and adding to the prosperity of many small manufacturers who made parts for automobiles as well as related devices or who made machine tools.

Some newly emerging technologies were not immediately accepted, however; paradoxically, the automobile and the truck are good examples. When Karl Benz built his first automobiles in the 1880s, there was generally no perception of a need for such vehicles — the public became interested in automobiles only about 20 years later. Trucks underwent the same fate. Developed in the 1890s, it was only after they had proved their usefulness during World War I that they became fully accepted in the United States, although

a study at Cornell University in 1900 had shown that their operation was 25 to 40 percent cheaper than that of the horse-drawn wagon.

The same delay in acceptance occurred with farm tractors. Although tractors equipped with internal combustion engines were available before World War I, farmers, especially in Europe, used them reluctantly, and many relied on horses until the 1960s. One reason for the slow acceptance of the tractor was that it went against farmers' tradition of self-sufficiency: Farmers could breed their own horses and feed the animals with their own crops. Horses and other livestock also produced manure to fertilize the farmers' fields. The tractor made farmers more dependent on outside sources for fuel, replacement parts, and fertilizer.

The spread of technology increased the demand for energy during the first decades of the 20th century. The oil industry quickly converted to the production of gasoline, introducing new methods, such as cracking petroleum to produce specialized hydrocarbons. Coal remained the main source of energy, however, and the rapidly spreading electric power stations became its largest consumers.

Electricity: a revolution in technology

Although electricity had been studied since the 18th century — it was then more a subject of curiosity and entertainment — the widespread introduction in the workplace during the 1880s caused a profound change of technology. Electricity was the first practical way to transport energy over long distances between central power stations and homes or factories. It also allowed the construction of numerous new devices that were impractical by mechanical means only. The electric magnet, whether in electric motors, electric relays, or electric mechanisms of other

kinds, became the core element of a new technology that quickly developed: electrotechnology. Thermostats, servo-mechanisms, and a large number of automatic systems became based on electricity. The use of electricity allowed the construction of machines that in pure mechanical form would be impracticable because of friction and inertia. Many formerly mechanical devices became much smaller, more efficient, and faster through the introduction of electric components. The transition from purely mechanical devices to electromechanical devices is comparable to the transition, after World War II, from electromechanical devices to purely electronic devices.

The introduction of the electric motor made possible the development of underground railways (subways). Internal combustion engines such as diesels are not suited for use underground because of their need for oxygen and even more because of problems caused by the products of combustion that they produce. Electrotechnology also allowed the development of automatic switching systems and safety systems in railways, a development that with mechanical devices alone would have been impossible.

Electric power, still supplied by small power stations at the turn of the century, became more centralized because of the availability of large steam turbines and electric generators. The first electric power stations were built close to consumers to minimize the losses caused by the resistance of electric wires. The transformer was a very important invention: It permitted the transformation of the voltage of generators to high values so that electric energy could be transported over much longer distances with very little loss. The establishment of high-voltage distribution systems of electricity ultimately freed industry from geographical constraints. Earlier, industry would establish itself where

energy was available, either waterpower or coal. Now it could establish itself wherever there was electric power, or almost everywhere. For example, when the hydraulic power station at Niagara Falls was completed in 1886, it attracted several new industries using electric motors to drive their machines.

Although factories in which a central steam engine powered the majority of machines through a system of belt transmissions existed until the end of the 1960s (the important Bowler machine shop in Bath, England, used this method until it went bankrupt in 1969), industry converted from the early 1900s on to machines driven by independent electric motors. The electric motor, cheap and easy to operate, also stimulated the creation of numerous small workshops with a few machines each. Electricity-producing companies encouraged this development by offering cheap industrial rates. In the early days of electric power generation, electricity served only for lighting, so demand was high during the evening hours and very low during the day. The increased use of electric motors by workshops and industry evened this imbalance.

Science and technology

A new type of laboratory emerged during the 1880s, a laboratory for testing safety, especially the safety of railway systems. Such laboratories appeared first in Germany, but also in the United States. Besides testing, scientists became involved in the development of new products.

The necessity for engineers to rely on science and scientific research became apparent in many other areas. German chemical industrial labs were followed by laboratories for electricity and electronics. Although Edison was able to experiment with the electric bulb, ignoring Ohm's law, and Zénobe

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Gramme built his electric generator knowing little of physics, early developments in radio communication and electronics required a much better understanding of the physics at the base of these devices.

Large companies, including General Electric, Du Pont, and Bell Telephone, established research laboratories. Their aim was to develop or even invent new products. Researchers at several of these laboratories were given free rein and often ventured into basic research. Some of these industrial laboratories developed into cradles of experimental and fundamental science, on a par with the best university laboratories.

Major advances

ANTHROPOLOGY In 1895 Eugène Dubois brought to Europe his Javanese fossils of what we now call *Homo erectus* (the “Java ape-man”), the first hominid that most anthropologists considered a different species from *H. sapiens*. Dubois’ discovery met considerable resistance and he eventually took his specimens and hid them under floorboards of his house. In the early 20th century, however, more fossils of *H. erectus* were found in China and Africa, confirming the new species. Sadly, one of the greatest collections of *H. erectus* fossils, the “Peking man” specimens, was lost during World War II and has never been found.

The other great discovery in physical anthropology during the period started when Raymond Dart was given the fossilized head of a child to examine. He correctly recognized that the “Taung child” represented a new genus, closely related to *Homo*, which he named *Australopithecus*. As with the Dubois discovery, Dart’s ideas were rejected at first, but a search for other fossils of australopithecines, as the members of the new genus are called, produced many new fossils and was eventually

convincing. Interpretation of the meaning of the new species is still ongoing.

Our view of our more recent ancestors had been changed considerably by the discovery of a young girl in 1879, when the Altamira Cave paintings were found. However, this discovery was rejected as a fake until the beginning of our period. Discovery of the La Mouthe Cave paintings by four boys in 1895 reduced the cries of forgery to whispers. With other examples found in 1896 and 1901, the reality of Paleolithic art was beyond question. When four other young boys found the Lascaux Cave paintings in 1940, the greatness of some of the Paleolithic artists was also realized.

This period also includes virtually all of the development of cultural anthropology. Although the earlier 19th century included some studies of American Indians, the history of cultural anthropology is usually taken to begin in 1896 with Franz Boas’s department of anthropology at Columbia University, the first such department anywhere. Another major factor was the expeditions of the American Museum of Natural History (in New York), starting in 1900, to study the peoples of eastern Siberia to see whether they are the ancestors of American Indians. The major works of Bronislaw Malinowski during World War I and, immediately after, Margaret Mead during the 1920s and Ruth Benedict in the 1930s seemed to define cultural anthropology.

ARCHAEOLOGY Certainly the most astonishing achievement of archaeology during this period was the discovery of the Minoan civilization on Crete by Arthur Evans beginning in 1900. Like Schliemann before him, Evans was guided in part by legend and literature. The palaces and plumbing of Knossos, the principal city of the Minoan civilization, dazzled the world, although inability to read the inscriptions frustrated everyone. (This would be par-

tially resolved in 1953 when Michael Ventris deciphered one of the two forms of Minoan script.)

Almost as astonishing was the discovery in 1911 of Machu Picchu in the Peruvian Andes by Hiram Bingham. Bingham was looking for the retreat to which the last Inca (the ruler of the people also called Inca) had fled during the Spanish conquest, a city never seen by Europeans. On top of a high mountain, he found a royal estate and religious retreat containing some 200 buildings. Although it seemed quite ancient when found, it is now thought to date from about the middle of the 15th century. It was not the refuge of the last Inca, but because the Spanish did not know about it, it is one of the few Inca sites not partly destroyed after the Spanish conquest in 1532.

Finally, we cannot leave out the most famous discovery of all, Howard Carter’s finding of the tomb of Tutankhamen in 1922. Because of the treasure and legends associated with the find, “King Tut” came to represent the type of discovery that was the goal of archaeologists in the early 20th century.

At the same time, however, archaeology was turning away from searches for spectacular finds and turning toward a more scientific study of the past, a trend that would accelerate after World War II.

ASTRONOMY At the beginning of the 20th century astronomers held that the Sun was one of the many stars comprising a huge system called the Milky Way that filled the entire universe. Many of the fuzzy objects that had been observed for over 200 years, such as the Andromeda Nebula, were believed to be objects within the Milky Way Galaxy. An important breakthrough — the discovery that one could determine the distance of a certain type of variable stars, the Cepheids, by observing the variation period — allowed astronomers to measure the distance of some of the closer

"nebulae." By observing Cepheid variables in the Andromeda Nebula, Edwin Hubble discovered that it was at an enormous distance from our galaxy, and that in fact it was a galactic system comparable in size and shape to our own.

From the spectra of galaxies Hubble could derive their velocity relative to us. From this, he made a second surprising discovery. During the 1920s he found that the greater the distance of a galaxy, the faster it is moving away from us. This discovery formed the observational basis of the model of the expanding universe and the big bang.

In solar system astronomy, the most notable achievement was the expansion of the solar system to nine planets with the discovery of Pluto in 1930. Today, however, Pluto still seems to be an unlikely addition to the system, and it is not clear what its significance is.

A major achievement of astronomy during the period was the development of understanding of the life cycle of a typical star. As stars were classified into gas giants, white dwarfs, and so forth it became apparent that stars of different ages tended to fall into certain categories. The Hertzsprung-Russell diagram showed these relationships graphically.

BIOLOGY The foundations of experimental biology were laid during the 19th century. Fundamental research in heredity started with the rediscovery of Mendel's work by de Vries, Correns, and Tschermak in 1900. The concept of a "gene," a unit of inherited characteristics, such as the color of a flower, or in humans the color of the eyes, made it possible to understand how these characteristics were transmitted through generations. The role of genes in the production of enzymes in the cells of organisms also became understood and led to the "one gene, one enzyme" theory. What the compound was that contained the genetic information became clear only during the early 1940s, when

biologists discovered that DNA is the substance that transmits genetic information.

The role of mutations, sudden changes in the transfer of inherited characteristics, became clear in the mechanism of evolution. The fruit fly, in which the four chromosomes are clearly visible, and many mutants are clearly distinguishable (for example, by the shape of wings), became the most important subject for the study of mutations.

Biology gained enormously from the advances made in chemistry, especially from the study of organic compounds. The application of chemistry to biology gave rise to a new important discipline, biochemistry.

The role of certain substances, such as enzymes and hormones produced by living organisms, became understood, and the importance of hormones to many disorders, such as diabetes, was recognized.

CHEMISTRY With the understanding of the structure of the atom, chemists could explain many of the chemical properties of elements and compounds.

Scientists recognized that the periodicity of the chemical characteristics in Mendeléev's table reflected a periodicity in the configuration of the electrons in the outer layer of an atom. It is possible to explain the chemical properties of elements uniquely by the configuration of these outer electrons of the atom. The development of the theory of chemical bonding by Linus Pauling in the 1930s explained the role of electrons in the formation of molecules: Atoms could be bound together either by electrostatic forces (ionic bonding) or by sharing electrons (covalent bonding). The newly developed quantum mechanics formed the theoretical underpinnings of the study of chemical bonding and the interpretation of atomic and molecular spectra, making spectroscopy a power-

ful analytical tool. Spectroscopy was used not only in visible light but also in infrared and microwave regions of the spectrum.

Reaction mechanisms also were the objects of a large number of studies. The study of polymerization reactions led to the development of many compounds made up of macromolecules, such as artificial fibers and the first plastic materials. The chemistry of silicon, which can form complex compounds similarly to carbon, led to the development of the synthesis of silicones, which became important industrial compounds after World War II.

COMMUNICATION The telephone had a profound influence on society, bringing instant communication to the home. Broadcasting also played an important role in changing the society of the 20th century.

The telephone as well as the early radio communication devices were electromechanical devices rather than electronic ones, although the crystal detector, developed in 1901, can be viewed as the first electronic device in the modern sense. The discovery of the vacuum tube increased substantially the technical possibilities of telephone and radio communication, mainly because vacuum tubes can amplify weak signals or function as oscillators or rectifiers. Vacuum tube amplifiers allowed telephone signals to travel over thousands of miles, and radio communications to span continents.

The development of communications using electricity and electromagnetic waves is probably the chief technological factor that influenced society in the 20th century. Radio, and later television, also played an important role in society's acceptance of new inventions during the 20th century, spreading ideas swiftly through even illiterate populations. Sound recording and broadcasting also had a profound impact on culture. Just as printing

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made literature accessible to everyone, now music came into the lives of all people.

Motion pictures, after groundwork in both the United States and France, and made practical by the invention of celluloid film, developed quickly and became an important form of entertainment. Sound motion pictures became a reality during the mid-1920s and color pictures appeared in the 1930s. This rapid progress in less than 40 years culminated in the most famous movie ever made, *Gone with the Wind*, a color sound film of 1939 that had the largest number of viewers in the history of film until very recent times.

Often overlooked because of the revolutionary development of broadcasting, printing and typesetting advances in this period changed the way that books, magazines, and newspapers were created. Among the advances were the ways in which printers reproduced photographs, especially color photographs, the ways in which type was set (even the Linotype, which seems almost primitive today, was first introduced at the beginning of this period), and the use of offset printing. The creation of publications, as well as private and business correspondence, was also revolutionized by rapid advances in the mechanical typewriter. The electric typewriter did not achieve widespread use until after World War II, however.

COMPUTERS Some of the first working electronic computers were the result of military needs. The mathematician Norbert Wiener developed an electronic gun-pointing device based on a feedback mechanism, and Alan Turing developed an electronic computer that could break successfully the almost unbreakable Enigma code used by German forces. Others, however, had preceded them. The first electronic digital computer was developed in the late 1930s and early 1940s by John Atanasoff and Clifford E. Berry for the pur-

pose of solving systems of equations. In the case of the Atanasoff-Berry Computer, or ABC, the war prevented complete development, as both inventors were drafted for other wartime duties. Nevertheless, ideas based on the ABC were used in creating ENIAC, the first general-purpose electronic digital computer, operational by 1945.

CONSTRUCTION Two important materials entered architecture and construction during the last decades of the 19th century: steel and concrete. Neither was new, but new applications became possible.

The Bessemer process allowed the manufacture of cheaper steel, suitable for construction. The Eiffel tower had demonstrated that the use of iron and steel is not restricted to bridges but also can be used in vertical buildings. Steel soon became an important component of skyscrapers, many-storyed office buildings that were first built in Chicago, Illinois, before the turn of the 20th century.

Reinforced concrete is made possible by the lucky coincidence that steel and Portland cement have the same thermal expansion coefficient, so changes in temperature do not cause serious internal stresses that would lead to cracks or other flaws. Reinforced concrete became a very important building material. Concrete gave architects much more freedom in their designs. For example, the homes designed by Frank Lloyd Wright and Le Corbusier made ample use of reinforced concrete, freeing them from the constraints of the traditional building materials.

EARTH SCIENCE From our perspective today, it is easy to see Alfred Wegener's theory of continental drift as the main event in earth science in the first part of the 20th century; but geologists during this period generally rejected Wegener's ideas. These were not to be generally accepted (in a somewhat modified form) until the 1960s.

Most of the progress in geology that was recognized at the time came from the use of earthquake waves to determine the internal structure of Earth. It was during this period that geologists discovered that Earth has a crust, a mantle, an outer core, and an inner core. The knowledge of radioactivity quickly led to the idea that the age of a rock could be determined from the ratio of a radioactive element to its stable decay product. This period also marks the beginning of the systematic study of volcanoes.

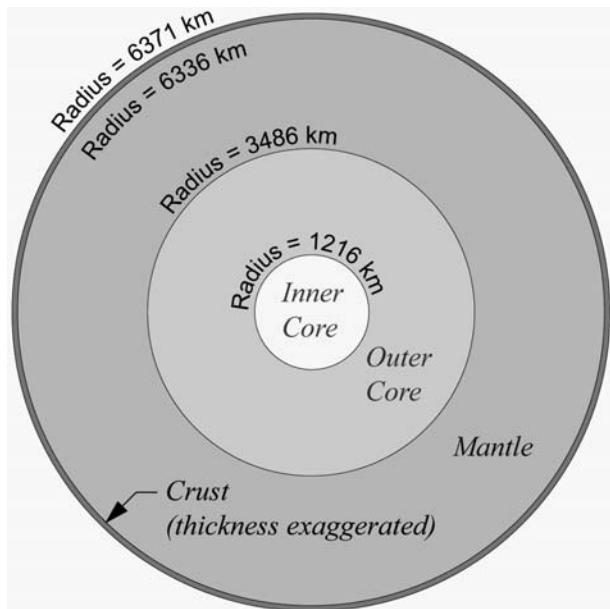
Oceanography benefited from the German *Meteor* expedition, which used sonar to discover the mid-Atlantic ridge. William Beebe also began the first efforts to explore the deeper parts of the ocean. Oceanography would not fully become a science, however, until after World War II.

Another part of earth science that saw progress was meteorology. The role of air masses was identified and groundwork was laid for numerical methods of weather prediction.

ELECTRONICS In the 20th century the extent of the dependence of technology on basic science became clear. The discovery of the electron gave rise to an entirely new technology, electronics. This was comparable to the development of the chemical industry in Germany during the 19th century based on discoveries in chemistry.

Not everyone agrees as to what distinguishes an electronic device from an electric one. Many define a circuit as "electronic" if it incorporates components that do not respond linearly to changes in current or voltage. Vacuum tubes fulfill this requirement, but electric motors or heaters respond directly to the amount of current. The development of the vacuum tube (or *valve* in evocative British English) was the most important factor in the evolution of electronic technology. Diode vacuum tubes served for the detection of radio

THE INTERIOR OF EARTH Before effective seismographs were invented early in the 20th century, scientists had learned two things about Earth's interior: it must be hot since it produces lava and deep mines have hot walls; and it must have parts that are heavier than stone, a result derived from density measurements. Reflected and refracted earthquake waves, however, reveal that Earth consists of several separate layers of material with one — the outer core — liquid.



waves, and triodes became widely used for amplifying radio and audio frequencies. In a triode, a small change in the current in the middle grid controls the passage of a much larger current between the two outer grids, permitting amplification of the current that flows through the middle grid. The development of tetrodes and pentodes (tubes with one and two extra grids) increased their suitability for a range of applications. During the 1920s and 1930s, their use expanded into television, sound recording and sound film, scientific instruments, radar, and, at the end of World War II, early electronic computers. In computers vacuum tubes became part of logical circuits, such as flip-flops (circuits that can occupy two electric states, such as a toggle switch).

ENERGY Coal remained the chief source of energy throughout the end of the 19th and the first half of the 20th century. For example, in 1900, 92 percent of energy in the world was supplied by coal and only 3.5 percent by petroleum. Coal mining became mechanized with the introduction, starting

in the 1860s, of coal-cutting machines that operated underground and giant excavation machinery used in open-pit mines. Coal remained the main energy source for steam power, railroad locomotives, steamships, the steel industry, and gasworks. Most of the electric power stations ran on coal, but an increasing part of electricity was generated hydraulically, especially in mountainous countries such as Italy or Canada. Gas produced from coal served for lighting until the arrival of electricity.

Toward the end of this period, vehicles powered with diesel engines began to become commonplace. In the United States, General Motors was able to use its near monopoly to replace electric-powered tram lines in cities with diesel-powered buses. High-speed passenger trains also began to use diesel locomotives. Other heavy equipment, such as earth-moving machinery, gradually shifted from steam power to diesel as well.

FOOD & AGRICULTURE Handling of food at both the production end and in the kitchen changed dramatically during this period. The main agent of change

in production was the steady improvement of the tractor and its increased use on farms in Europe, but especially in North America, where a tradition of large fields had developed to take advantage of mechanical planters and reapers. Farms were rebuilt by removing stone walls or brush hedges to make for still larger fields that took better advantage of the power of the tractor. Other mechanized farm equipment was also improved, but with few dramatic breakthroughs — a lot of the development was plagiarized from the growth of the automobile and truck industries. The self-propelled combine was one noticeable step forward, however.

Although one thinks of mechanization of farming in terms of planting and harvesting crops, herding was also partly mechanized during this period, primarily in the way milk came to be extracted from cattle with mechanical milkers and in the way milk was separated and stored after milking.

At the end of this period, signs of the next great change in agriculture became apparent with the recognition of potent insecticides and selective herbicides.

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In the kitchen, the electrification of small appliances was the main change. With electrification, brand new appliances, such as the blender, were invented. Although freeze-drying and freezing were introduced in this period, they did not affect the way people lived until after World War II. One significant change in eating habits at home came with the introduction of prepared breakfast cereals; previously, breakfast cereals, when they were eaten at all, consisted of cooked grains, such as oatmeal. A sign of eating habits to come took place outside of the home: Cafeterias and restaurants where the patrons did not sit at tables were the precursors of the fast food establishments of today.

MATERIALS The technology of new materials, based on chemistry, made an enormous leap forward during the second half of the 19th century. Organic chemistry had opened up a Pandora's box of new products, especially dyes. Although the first artificial dyes were developed in England, the major development of the organic chemistry-based industry took place in Germany. Because of its colonies, a rich source for natural dyes, industrialists in England showed little interest in synthetic dyes.

From 1850 on, Germany became practically the sole manufacturer of dyestuffs. Because of fierce competition between dye-producing companies, it became important to come up continuously with new dyestuffs; this was the reason that industrial research laboratories appeared in Germany during the 1850s. In the 1880s large firms, such as the Badische Anilin und Soda-Fabrik (BASF), introduced modern industrial research methods based on research methods at German universities. The result was that linen and cotton could be dyed in a much wider variety of colors than previously possible, and people started wearing clothes with brighter and different colors.

Probably the most important result of

the flowering of the chemical industry during the end of the 19th century was the development of many new materials. Several of these materials contributed to the development of other technical fields. Celluloid, because of its transparency and flexibility, became the chosen material for the film industry. Bakelite, derived from phenol and formaldehyde, because of its properties as an electric insulator and because it is easily molded, became the material of choice for many electric and radio components, such as switches, control knobs, and vacuum tube sockets.

Industrial chemists, especially in Germany, set out to develop substitutes for organic materials such as rubber or fibers because of their high cost or unavailability. Scientists at German industrial laboratories discovered many plastic materials during the 19th century, but these products became commercially available only much later, in the first half of the 20th century.

The introduction of new artificial fibers had a large impact on the clothing and fashion industries. In the 1920s, rayon, also known as artificial silk, started replacing cotton in clothing, making low-cost fashionable clothing widely available. The most spectacular of new man-made fibers was nylon, discovered in 1938 by Wallace Carothers. Nylon first became famous as the material of choice for women's stockings, but later it was used in applications such as rope and carpeting because of its intrinsic toughness.

During the first decades of the 20th century, reinforced concrete became the building material for bridges, factory buildings, military fortifications, roads, and even homes.

MATHEMATICS During the end of the 19th century, mathematicians had engaged in a massive effort to develop a purely logical basis to mathematics. One of the first attempts to find an axiomatic basis for mathematics was

undertaken by David Hilbert. He proposed that a system of mathematical foundations should satisfy three requirements: It should be consistent, complete, and decidable. The existence of infinite sets, however, led to paradoxes. In 1931 Kurt Gödel proved that Hilbert's ideas could not be realized: Mathematics could not be both consistent and complete.

Alfred North Whitehead, Bertrand Russell, and Giuseppe Peano extended algebra from symbols for numbers to symbols for concepts, creating symbolic logic. In France during the 1930s, a group of mathematicians working under the pseudonym of N. Bourbaki started the task of giving mathematics an axiomatic basis by searching for those structures that form the basis of the different mathematical theories. Another group, led by Emmy Noether at Göttingen in Germany, developed abstract algebras that could represent any type of system.

The concept of an integral had been generalized by Bernard Riemann and T. J. Stieltjes in the 19th century, but the definitive expansion of the definition came in 1902 in connection with the measure theory of Henri Lebesgue. In turn, Lebesgue's work combined with set theory and topology, also 19th-century ideas, merged into the new discipline of functional analysis, the mainstream of analysis in the 20th century.

Other developments were so numerous that they can only be mentioned here: the axiomatization and extension of probability, algebraic geometry, optimization theory, analytic number theory, the theory of integral equations, and stochastic processes, among others. Mathematics in the 20th century reached the extent that science had in the 19th. No longer could any one mathematician be competent in all branches of the subject.

MEDICINE & HEALTH The identification of organisms causing disease, started in

the 19th century by a number of scientists such as Koch and Pasteur, continued throughout the 20th century. Also, several of the toxins secreted by microorganisms, often the compounds causing the disease, became identified.

The role of hormones and certain important agents in food, called vitamins, became clear in health care. During the first decade it was discovered that the absence of thiamine is the cause of beriberi and the absence of insulin production is the cause of one type of diabetes. Diabetes became treatable by the administration of insulin extracted from animals.

Psychology made further progress and was often based on experiments with animals. The importance of childhood experiences and sex in the development of affective disorders was emphasized in the work of Sigmund Freud, who influenced society at large, as well as science. Several schools of psychological thought developed, each with different forms of treatments for psychic disorders.

More than any other discipline, medicine profited from many discoveries in the life sciences, chemistry, and physics during this period. In physics, the discovery of X rays was probably the most important finding, not only for setting broken bones, but in the improvement of diagnostic medicine generally. Another important finding based on physics, by Dutch physiologist Willem Einthoven, was the tiny electric currents generated by the heart muscle. By studying a graph of heartbeat-produced voltages, physicians found abnormalities of the heart that would otherwise be difficult to detect.

The discovery of large numbers of microbes and small protozoans that cause disease was followed by the introduction of better hygienic measures for avoiding contamination. The search for the agent causing syphilis was started on a grand scale in both Germany and

France. It resulted in the discovery of the microbe that causes the disease in 1906 and the subsequent Bordet-Wassermann test for syphilis. Scientists also discovered drugs that could destroy specific disease-causing microorganisms.

Alexander Fleming uncovered the most powerful agent for killing bacteria in 1928, a mold of the strain *Penicillium*, the source of the chemical penicillin. Because of the difficulty of obtaining penicillin in sufficient quantity, it became widely available only during World War II, after a major research program in the United States found ways to grow the *Penicillium* mold in vats as yeast is grown. Streptomycin also became available during the war for use against tuberculosis. The availability of effective antibiotics, and a better understanding of the transmission mechanisms of disease, has caused many diseases to be nearly eradicated.

For a long time viruses as the causative agent of disease remained undetected. However, in 1908 Karl Landsteiner isolated the poliomyelitis virus. The electron microscope, developed during the 1930s, made it possible to examine viruses directly. However, viruses were found to be untouched by the antibiotics that were so deadly to bacteria; such antibiotics interfere with development pathways in bacteria that are not shared by either humans or viruses. An improved understanding of the immune system became the only path to fighting viral diseases. By the end of the 19th century, several researchers, including Louis Pasteur, Robert Koch, Emil Behring, and Shibasaburo Kitasato, understood the role of the immune system in fighting bacteria and had developed several vaccines. Viral vaccines became available later.

In 1910 Peyton Rous showed that viruses play a role in cancer when he discovered chickens that suffer from certain sarcomas caused by viruses.

Until the end of the 19th century, cancer often went undiagnosed, but throughout the 20th century, the incidence of all types of cancer became increasingly noted. The cause of cancer remained little understood, although scientists began to recognize that cancer could be caused by chemicals and by radioactivity. Surgery was the main method of treatment in the first half of the 20th century, even though the effect of X rays in destroying tumors had been discovered at the beginning of the century.

PHYSICS Physics underwent a revolution during the first decades of the 20th century. Ideas about space and time, continuity, and cause and effect, which were the underpinnings of Newtonian mechanics, changed fundamentally because of two important developments: the introduction of relativity theory by Einstein and the advent of quantum mechanics. The first development, however, was the understanding of the structure of the atom, brought about by a series of important discoveries.

Until the end of the 19th century, physicists assumed that all phenomena encountered in physics could be explained by the motion of particles following Newton's laws of motion. However, the classical theory could not explain the repartition of energy in the molecules of a gas and the energy distribution of radiation emitted by hot bodies. These problems led Max Planck to announce in 1900 a revolutionary postulate in physics: Energy can only be given off by matter in small packets, called quanta. What exactly these quanta were became clearer in 1905 when Einstein introduced the concept of the photon: Light travels in small packets called photons. This was reminiscent of Newton's idea that light consists of vibrating particles. According to Einstein, light is only emitted in small packets, but it also can only be absorbed in small packets.

Rise of Modern Science and Technology: 1895 through 1945

One of the major problems that physics solved at the end of the 19th century was the nature of cathode rays. The discovery that these rays consist of minute particles with negative electrical charge (electrons) and the discoveries of X rays and radioactivity opened the way to the understanding of the structure of the atom during the first decades of the 20th century. Ernest Rutherford succeeded in identifying the particles that were emitted by radioactive substances and the changes in the atoms that emitted these particles. By bombarding atoms with alpha particles, Rutherford found that some alpha particles were deflected from their path almost directly back along the same path. From this observation he concluded that an atom must consist of a very dense nucleus of positive charge around which revolve electrons like planets in a miniature planetary system.

The model of the atom described by Ernest Rutherford in 1911, a nucleus around which pointlike electrons orbit like planets, had an important flaw. The moving electrons should emit electromagnetic waves, gradually lose energy, and ultimately fall onto the nucleus. Niels Bohr solved this problem by introducing a model of the atom that incorporated a principle similar to Planck's hypothesis of quanta: Electrons occupy fixed energy levels in the atom and can only absorb or emit energy by jumping from one energy level to another. Bohr's model of the atom also explained the spectrum of the hydrogen atom.

Bohr's theory, however, was still fraught with theoretical problems. For example, his theory could not explain the spectra of atoms more complex than hydrogen. Also, certain results of Maxwell's electrodynamic theory were inconsistent with other existing theories. In 1905 Einstein published his theory of special relativity, a theory of mechanics consistent with electrodynamics.

In 1915 Einstein published his general relativity theory, which solved problems with gravity that were not explained by the special theory. Special relativity theory also explained the negative result of the Michelson-Morley experiment, while general relativity explained the minute rotation of Mercury's perihelion, which had been observed earlier. In addition, Einstein's general theory predicted a specific amount that light would be bent by massive objects, one different from bending caused by Newtonian gravity. Einstein's predicted bending of light by mass was experimentally confirmed by an expedition led by Arthur Eddington that measured the displacement of a star close to the edge of the apparent disk of the Sun during an eclipse in 1919.

The first artificial nuclear reactions were achieved shortly before the Second World War by Lise Meitner, Otto Hahn, and Fritz Strassmann. This led to the development of the atomic bomb during World War II.

TOOLS During the early part of the 19th century, machines, railway cars, and engines nearly always were built entirely by hand by skilled workers using a variety of tools. Machines were used in special applications, for example, the boring of steam cylinders, mainly because machines allowed the creation of cylinders of much greater precision. The gradual introduction of several types of tooling machines not only accelerated the manufacture of metal parts and other devices, but also improved the precision with which these devices were built. The manufacture of machine tools, sometimes called "the industry of industry," became the backbone of commerce. Lathes, milling machines, and boring machines served for the manufacture of all kinds of objects, but also for the creation of better tooling machines themselves.

The cutting and grinding tools of

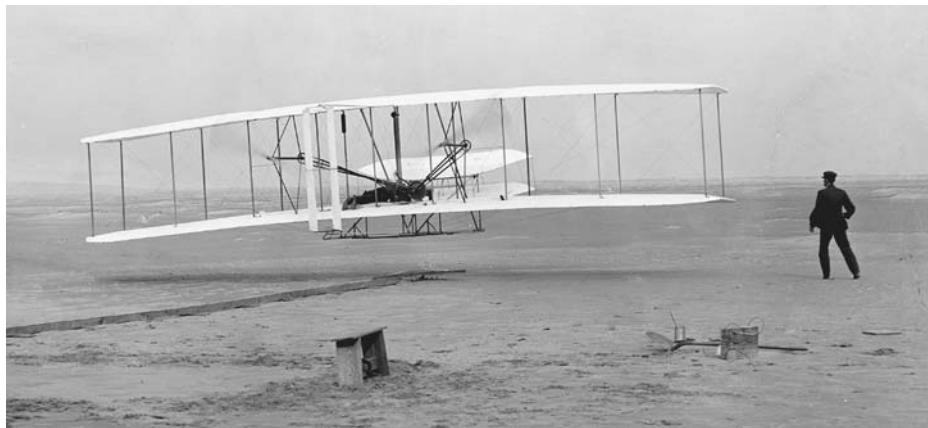
these machines consisted of carbon steel that had to be much harder than the material of the workplace. The cutting speed attainable with these tools was between 5 and 10 m (15 and 30 ft) per minute. The invention of the so-called high-speed steel allowed cutting speeds that were much higher; by 1912 cutting speeds of 30 to 50 m (90 to 150 ft) per minute were common. During subsequent years, even harder and more heat-resistant alloys were developed, allowing the manufacture of metal parts in a fraction of the time required by the older carbon-steel tools.

TRANSPORTATION The development of the automobile is often viewed as the direct consequence of the development of the internal combustion engine.

Interestingly enough, most automobiles built around the turn of the century were not powered by internal combustion engines. For example, in 1900, of the 4192 cars manufactured in the United States, 1681 were equipped with a steam engine, 1575 with an electric motor, and 936 with an internal combustion engine. During subsequent years, the balance tipped in favor of the gasoline engine. However, during the beginning of the time of car manufacturing, it was not clear that the internal combustion engine would win out over other engine types. Even experiments with early airplanes showed that the steam engine could be turned into a lightweight power source. Clement Ader's first airplane, in 1890, the *Eole*, was equipped with a steam engine that weighed 15 kg per horsepower. His second airplane, the *Avion III*, completed in 1897, was equipped with two small steam engines weighing 3 kg per horsepower, something that could not be attained with an internal combustion engine at the time. For example, the airplane of the Wright brothers that flew in 1903 was powered by an internal combustion engine weighing 6 kg per horsepower.

WRIGHT BROTHERS AND THE FIRST FLIGHTS

The first half of the 20th century saw the transition from the Wright Brother's *Flyer* of 1903 shown here, with flights that lasted less than a minute, to airliners that could carry dozens of passengers on flights across the world's oceans. Orville, lying on the lower wing, steers by moving his hips in a special cradle while Wilbur, running alongside, has just released his hold on the plane, which was needed to balance the *Flyer* while it was still on the ground.



In 1908 Henry Ford equipped his Model T automobile with a gasoline internal combustion engine; it was this model, of which there were 15,000,000 built, that set the stage for the further development of the automobile. Several improvements to the internal combustion engine made it eventually more suitable for mobile applications; among those improvements were electric ignition and the carburetor. Using high-energy, low-weight, low-volume fuel gasoline, a car powered by an internal combustion engine did not need to stop frequently to take in water or to have its battery charged.

During the first decades of the 20th century, the gasoline engine underwent further improvements. During the early years of the automobile industry, engines had low power output because "knock" limited the compression ratio in the cylinder. Knock is caused by the spontaneous ignition of the gas mixture before the piston has reached its highest position, causing loss of power, damage to the piston, and overheating. During the mid-1920s, gasoline that was more resistant to knock became available, and engines were built with higher compression rates and higher performance capability.

The development of airplanes was even more tightly linked to the development of the internal combustion engine. Two factors were important; the weight of the engine and the amount of power the engine could deliver. The "Gnome" engine that equipped airplanes during World War I weighed 1.5 kg per horsepower. This ratio was reduced to 0.5 kg per horsepower for airplane engines used during World War II. Supercharging — that is, the compression of air before it enters the cylinders — substantially increased the power achievable with airplane engines. Engines of a few hundred horsepower were available during World War I, but much more powerful engines were available during World War II. During World War II, both in England and Germany, engineers developed the turbojet engine. The turbojet engine is very efficient at delivering thrust at high speeds; it made possible the construction of very fast airplanes during the years after World War II.

Besides engines, airplanes underwent several other improvements. Instead of wood and fabric, manufacturers turned to aluminum for building airplanes, which allowed a much more aerodynamic shape. Also, retractable wheels

diminished the resistance of air at high speeds. The most successful plane developed before World War II was the Douglas DC-3, also known as the *Dakota*. Eventually, 15,000 DC-3 airplanes were built, and it became the workhorse of American forces during the war. The Clipper four-engine seaplane inaugurated transatlantic passenger service in 1939; however, this service was interrupted because of the outbreak of war.

In the 20th century, up to World War II, three coexisting technologies powered commercial and navy ships: sails, traditional steam engines, and the newly developed steam turbines. A few ships were also powered by diesel engines, which soon became the most popular choice for small- and medium-sized ships after World War II.

In the 1930s, a fierce competition started among England, France, and Germany for offering fast and comfortable passenger service between Europe and the United States. Each of these countries built giant ships that could cross the Atlantic Ocean in four days — the *Normandie*, the *Queen Elizabeth*, and the *Queen Mary* are examples.

CHRONICLE**1895****► Anthropology**

Eugène Dubois brings the fossils he had found of *Homo erectus*, which he calls *Pithecanthropus* and the public calls “the ape man of Java,” to Europe, where they are met with considerable skepticism.

On April 11, four boys in France who are playing in a cave called La Mouthe behind an old stone barn discover paintings of bison, ibex, and horses. Later investigation by an archaeologist also reveals a lamp decorated with an ibex, thought to have been used by the artist some time in the period from 15,000 to 13,000 BCE.

★ Astronomy

James Edward Keeler [b. La Salle, Illinois, September 10, 1857, d. San Francisco, August 12, 1900] observes Saturn’s rings and recognizes that they do not rotate as a unit, suggesting that they are formed of discrete particles, as James Clerk Maxwell had predicted.

► Biology

Ivan Petrovich Pavlov [b. Ryazan, Russia, September 26, 1849, d. Leningrad (St. Petersburg), February 27, 1936] lectures on his work that demonstrates that the stimulus that causes secretions from the stomach is mediated by the nervous system. He has pioneered the use of openings (fistulas) to the interior of organs to observe the effect of a stimulus immediately after the stimulus occurs. See also 1903 BIO.

Carl Rabl [b. 1853, d. 1917]

asserts that chromosomes keep their identity during cell division. This is an important point leading to the assumption that chromosomes are carriers of heredity. See also 1902 BIO.

□ Chemistry

William Ramsay discovers helium on Earth. It had been found in 1868 as an element in the Sun from observations of the Sun’s spectrum. Earthly helium is also discovered independently by T. Cleve. See also 1868 CHEM.

◄ Communication

Guglielmo Marconi receives radio signals transmitted from a distance of 2 km (1.2 mi).

French chemist and inventor Auguste Lumière [b. Besançon, France, October 19, 1862, d. Lyon, France, April 10, 1954] and his brother Louis Lumière [b. Besançon, October 5, 1864, d. Bandol, France, June 6, 1948] patent the *cinématographe*, a projection version of Edison’s Kinetoscope. The first public showing of a motion picture using their process to an audience takes place in a cafe in Paris in December (preceded in the United States by a crude projected version of a prize-fight in the spring that entrepreneurs using modified Edison equipment show). The Lumière brothers use 16 frames per second and 35-mm film, both of which become early standards for the industry. See also 1891 COMM; 1896 COMM.

In England, Karl Klietsch combines forces with printer Samuel Fawcett to develop an improved form of machine photogravure on copper plates. The method, nick-

named “Rembrandt” photogravure, is kept secret by the Liverpool firm that employs Klietsch and Fawcett, but others find essentially the same process and the method becomes generally used in the early 20th century. See also 1872 COMM.

Herman Castler patents the Mutoscope, inspired by Edison’s first version of a Kinetoscope. The Mutoscope consists of a large number of cards mounted on a rotating drum, which when viewed one by one in rapid succession create a moving image. Coin-operated versions of such machines soon appear in “picture parlors” in resorts. See also 1888 COMM.

John T. Underwood [b. London, April 12, 1857, d. Wianno, Massachusetts, July 2, 1937] begins to manufacture a typewriter patented in 1893 by Franz Xavier Wagner [b. Heimbach, Germany, May 20, 1837, d. New York City, March 8, 1907] that, like the Oliver typewriter of 1892, allows the operator to see the words as they are typed. See also 1872 COMM.

The first ballpoint pen that is commercially introduced is produced, although patents for similar pens occur throughout the 20th century. It will be another half century, however, before a version of the ballpoint becomes popular. See also 1888 COMM; 1938 COMM.

■ Construction

In response to a request to improve the sound of a lecture hall, American physicist Wallace Clement Ware Sabine [b. Richwood, Ohio, June 13, 1868, d. Cambridge, Massachusetts, January 10, 1919] becomes the first acoustical

engineer. He develops a method to measure the time of decay of pure tones in a room when empty and when absorbing materials are present. He will use acoustic principles to design Boston’s Symphony Hall, which will open on October 15, 1900.

► Energy

At Niagara Falls, hydraulic electric generators installed by the Westinghouse Electric Company start operation, producing a.c.(alternating current) electric power of 3750 kW at 25 Hz, supplying the town of Buffalo, 35 km (22 mi) away, with electric power. See also 1882 ENER.

■ Food & agriculture

Charles William Post [b. Springfield, Illinois, October 26, 1854, d. Santa Barbara, California, May 9, 1914] begins his first health food business by marketing Postum, described as a “cereal food coffee.” See also 1897 FOOD.

◊ Materials

Independently, Karl von Linde and William Hampson [b. Cheshire, England, 1854, d. 1926] develop a regenerative (feedback) method of mass producing liquid air. The same method can be used to liquefy any gas except neon, hydrogen, or helium. See also 1784 MATR; 1908 MATR.

Σ Mathematics

Giuseppe Peano’s *Formulaire de mathématiques* (“formulation of mathematics”) uses the special symbolism for symbolic logic developed by Peano to express many of the fundamental definitions and theorems of mathematics; by



INSIDE THE NIAGARA FALLS POWER HOUSE NO. 2 The first Niagara Falls Power House was built between 1892 and 1894, opening for business in 1895. Its immediate success brought industry into the Buffalo region and Power House No. 2 was built between 1901 and 1903. Other generating facilities were built around the same time, each collecting some of the energy from the Falls and converting it to electricity.

its fifth and last edition in 1908 (as *Formulario matematico*) it contains about 4200 theorems. See also 1854 COMP.

"*Beitrage zur Begründung der Transfiniten Menglehre*" ("contributions to the founding of the theory of transfinite numbers") by Georg Cantor is a survey of Cantor's work that will initiate and develop set theory. About this time Cantor discovers the self-contradiction

diction that comes to be known as the paradox of Burali-Forti, since Cesare Burali-Forti rediscovers it in 1897 and publishes it. The paradox concerns infinite ordinal numbers: The ordinal number of the series of ordinal numbers is not itself found in the series. See also 1899 MATH.

Emile Borel introduces the concept of a metric of a set, or

Borel measure, the first effective way to measure sets of points. This becomes one of the fundamental ideas behind modern theories of integration as well as of such branches of mathematics as functional analysis and algebraic topology.

Analysis situs ("place analysis") by Jules Henri Poincaré [b. Nancy, France, April 29, 1854, d. Paris, July 17, 1912] founds topology as a branch of mathematics (although a few theorems now recognized as topology had been proved previously). See also 1882 MATH.

♥ Medicine & health

G.V. Black standardizes procedures for dental filling and shows that mercury-silver amalgam is safe to use in dental fillings despite the poisonous nature of mercury.

Josef Breuer [b. Vienna, Austria, January 15, 1842, d. Vienna, June 20, 1925] and Sigmund Freud publish *Studies in Hysteria*, which describes their "talking cure" and is generally considered to be the beginning of psychoanalysis. See also 1885 MED; 1900 MED.

⌘ Physics

Wilhelm Konrad Roentgen [b. Lennep, Germany, March 27, 1845, d. Munich, Germany, February 10, 1923] discovers X rays on November 8; he finds that these rays pass through opaque matter, a property that immediately leads to their application in diagnostic medicine. See also 1896 MED.

Jean-Baptiste Perrin [b. Lille, France, September 30, 1870, d. New York, New York, April 17, 1942] shows that cathode rays

deposit a negative electric charge where they impact. See also 1897 PHY.

Pierre Curie shows that as the temperature of a magnet is increased, there is a level at which the magnetism is disrupted and ceases to exist. This temperature is still called the Curie point.

George Fitzgerald proposes that distance contracts in the direction a body is traveling, keeping the velocity of light uniform. This effect has come to be known as the Lorentz-Fitzgerald contraction, as Hendrik Lorentz independently makes the same suggestion.

Hendrik Lorentz shows that a moving charged particle will have a force exerted on it by electric and magnetic fields (the Lorentz force).

I Tools

Charles Thomson Rees Wilson [b. Glencorse, Scotland, February 14, 1869, d. November 15, 1959] invents a device that will produce a small cloud in a closed box — the cloud chamber. See also 1899 PHY; 1925 PHY.

↗ Transportation

Konstantin Tsiolkovsky publishes his first scientific papers about space flight. He proposes that liquid-fueled rockets can be used to propel vehicles in space. Because of his priority in this field, Russians refer to him as the father of space flight. See also 1892 TRAN.

Scottish engineer Percy Sinclair Pilcher [b. Bath, England, 1866, d. Stanford Park, England, 1899] starts experiments with kites and gliders in hopes of developing heavier-than-air craft. See also 1894 TRAN; 1900 TRAN.

Invisible radiation

Visible light has been known since organisms developed eyes. Today we pluck long waves of invisible radiation from our surroundings with cell phones, television receivers, and radios, while we wear sunglasses and sunscreen in part to protect against shorter waves that we cannot see. The perception that invisible radiation pervades the universe, however, is relatively new. In 1800 William Herschel discovered that invisible rays, now called infrared radiation, heat a thermometer better than visible sunlight. The following year Johann Bitter found the other side of the story: Invisible ultraviolet radiation affects silver chloride more than light does.

Like most discoveries of invisible rays, the discoveries of Herschel and Bitter were accidental. The next discovery however, was predicted. In 1873 James Clerk Maxwell incorporated infrared and ultraviolet radiation along with visible light into his theory of electromagnetic waves. Maxwell's theory forecast that radiation with wavelengths longer than infrared and shorter than ultraviolet should exist. In 1888 Heinrich Hertz was able to use Maxwell's theory to produce and detect the invisible long waves, which we now know as radio waves. But no one knew how to make the very short waves.

In the 19th century, however, one different form of invisible radiation was known. William Crookes, while trying to find whether electricity would pass through a vacuum, had discovered in 1878 that an invisible ray initiated by electric current could be detected by the fluorescence it produced where it struck. These rays, which proceeded from an electric terminal called the cathode, came to be known as cathode rays. In 1897 they were identified as streams of tiny charged particles (electrons), quite different from the electromagnetic waves analyzed by Maxwell.

Cathode rays were to lead to the next two accidents that uncovered new forms of radiation, which in turn started what some have called the second scientific revolution. In 1895 Wilhelm Roentgen was investigating materials that fluoresce when exposed to cathode rays. He had wrapped his tube in black paper, known to stop cathode rays, and was going to view a sheet coated with a fluorescent material in the dark. But he noticed that the sheet started to fluoresce even before he removed the black paper from his Crookes tube. Since Crookes had established that cathode rays do not penetrate such a shield, something else had to be causing the fluorescence. Roentgen took his fluorescent material into a closet, where it continued to glow whenever the Crookes tube was turned on. A series of experiments showed that this invisible radiation could pass through metals as well as through layers of paper, so it was not the same as the cathode rays. Roentgen had discovered X rays, the very short waves predicted by Maxwell's theory, although he initially failed to recognize them as short electromagnetic radiation. Within days of his announcement of these rays, doctors began to use them to aid in seeing inside the human body.

Within three months of Roentgen's announcement of X rays, another form of invisible radiation was found. Henri Becquerel thought that there might be X rays produced by fluorescent materials. He was working with a uranium compound that became fluorescent when exposed to sunlight. When he exposed a photographic plate that was wrapped in black paper to the fluorescing ura-

nium compound, he got a faint image on the plate. Luck brought Becquerel a series of cloudy days, so he could not expose the compound to sunlight. Becquerel left the sample and the wrapped plate in a drawer. When the cloudy weather persisted, he decided to develop the photograph anyway, hoping for a slight exposure. Instead, he found that the plate was heavily fogged. Radiation had been emitted by the uranium compound continuously, without the stimulation of sunlight.

Becquerel and other physicists soon found that the invisible radiation given off by the uranium compound — which in 1898 Marie Curie named radioactivity — consisted of three parts, alpha, beta, and gamma rays. Becquerel himself was the first to show that beta rays are the same as cathode rays; that is, streams of electrons. In 1900 Ernest Rutherford was able to show that gamma rays are basically the same as X rays, but with even shorter wavelengths. A few years later, Rutherford and Hans Geiger found that alpha rays are helium atoms that have been stripped of their electrons. In a sense, then, Becquerel's radioactivity was not a new type of radiation. Instead, its significance was that it was radiation spontaneously emitted by atoms. From that discovery, many others have flowed.



ONE OF THE FIRST X RAYS SHOWN TO SCIENTISTS Although not the first X ray photograph ever made, the photo traditionally known as "Mrs. Roentgen's hand," part of the first public announcement of the penetrating radiation, produced the most excitement and led to medical X rays within months. Mrs. Roentgen is reported to have "shuddered at the thought that she was seeing her own skeleton," but physicians recognized the opportunity for better care.

Otto Lilienthal and his brother Gustav [b. Auklam, Prussia, October 9, 1849, d. Berlin, February 1, 1933] design and fly the first glider that can soar above the height of takeoff. *See also* 1889 TRAN; 1896 TRAN.

1896

★ Astronomy

The first lunar photographic atlas is published by Lick Observatory, Mt. Hamilton, California.

John Martin Schaeberle [b. Württemberg, Germany, January 10, 1853, d. Ann Arbor, Michigan, September 17, 1924] observes the dark companion of the star Procyon for the first time, finding the second white dwarf known (after Sirius B). The observation of a second example leads to the correct idea that such dwarf stars might be common. *See also* 1862 AST.

◆ Biology

German chemist Eugen Baumann [b. Württemberg, Germany, December 12, 1845, d. Freiburg, Germany, November 3, 1896] discovers iodothyroin, an active agent secreted by the thyroid gland that contains essentially all of the iodine found in the human body; this leads to the use of iodine to treat and prevent thyroid disorders, such as goiter. *See also* 1914 BIO.

Charles Sherrington [b. London, November 27, 1857, d. Eastbourne, Sussex, England, March 4, 1952] gives the name *synapse* to the junction of two nerve cells. *See also* 1932 BIO.

◆ Communication

Eastman Kodak introduces the

Brownie camera, priced at one U.S. dollar. Millions of people will buy the simple camera and take hundreds of millions of photographs with it, buying most of their film from Kodak. If a customer takes more than 40 pictures (at the original price), he or she will spend more on film than on the camera; processing costs more as well. *See also* 1889 COMM.

Thomas Armat [b. 1866, d. 1948] of Washington, DC, develops a projector for motion pictures that permits the image to stay on the screen longer with shorter intervals between images. This device, the Vitascopic, greatly reduces the image flickering that had already given motion pictures their first nickname, the "flickers." *See also* 1895 COMM; 1900 COMM.

The telephone dialer is developed in Milwaukee by an inventor whose name is not known. Before this time, telephone connections could be made only by giving the number of the person to be reached to a telephone operator or, if an automatic exchange had been installed, by using a push button to produce the correct number of pulses for each number.

◆ Computers

Herman Hollerith, after successfully applying his punched-card technique to the U.S. Census, founds Tabulating Machine Company, which later changes its name to International Business Machines, and still later to IBM. *See also* 1890 COMP.

◆ Earth science

Svante Arrhenius calculates that the amount of carbon dioxide in the atmosphere

determines the global temperature and theorizes that the ice ages occurred because some process had reduced the level of carbon dioxide. Thomas Chrowder Chamberlin in a paper read to the British Association in Toronto, also points out that variations in the composition of Earth's atmosphere might have caused changes in climate in the past. *See also* 1894 EAR; 1906 EAR.

◆ Food & agriculture

Agricultural chemist George Washington Carver [b. near Diamond Grove, Missouri, 1864, d. Tuskegee, Alabama, January 5, 1943] becomes head of the Department of Agricultural Research at Tuskegee Institute in Alabama, where he will develop techniques for regenerating land by growing sweet potatoes and peanuts. He also will invent hundreds of new uses for both plants.

Donald Cameron of Great Britain devises the first septic tank that promotes anaerobic fermentation. *See also* 1885 ECOL; 1914 ECOL.

Selective weed killers are used in France. *See also* 1885 FOOD; 1940 FOOD.

◆ Materials

The invention of the alloy invar by Charles Edouard Guillaume [b. Fleurier, Switzerland, February 15, 1861, d. Sèvres, France, June 13, 1938], a metal with a very small expansion or contraction with temperature, solves the long-standing problem of compensating for the way that temperature affects the operation of the pendulum clock. Pendulums of invar instead of brass do not require compen-

sating mechanisms. *See also* 1726 TOOL; 1920 MATR.

Σ Mathematics

Jacques Salomon Hadamard [b. Versailles, France, December 8, 1865, d. Paris, October 17, 1963] proves the prime number theorem: The number of primes exceeding a value x is approximately $x/\log x$ (where $\log x$ is the natural logarithm, sometimes written $\ln x$, whose base is e) and this approximation improves as x increases toward infinity. The theorem is also proved independently by Charles-Joseph de la Vallée Poussin [b. Louvain, Belgium, August 14, 1866, d. Louvain, March 2, 1962]. *See also* 1876 MATH.

♥ Medicine & health

Michael Idvorsky Pupin [b. Idvor, Austria-Hungary, (Yugoslavia), October 4, 1858, d. New York, March 12, 1935] of Columbia University takes the first diagnostic X-ray photograph in the United States. Eddie McCarthy of Dartmouth, New Hampshire, has a broken arm set with the new diagnostic aid less than three months after the discovery of X rays by Wilhelm Roentgen. *See also* 1895 PHY; 1897 MED.

❖ Physics

(Antoine) Henri Becquerel [b. Paris, December 15, 1852, d. Le Croisic, Loire Inférieure, France, August 25, 1908], reacting to the recent discovery of X rays, continues his father's and grandfather's research on phosphorescence by starting an experiment aimed at looking for X rays from phosphorescent uranium salts. In the process he accidentally becomes on March 1 the first to observe

radioactivity. He identifies uranium as the source of the radiation and recognizes that the radiation is not X rays, although it shares some properties of X rays such as the ability to penetrate opaque objects. *See also* 1903 PHY.

In January Hendrik Lorentz uses observations of the behavior of light in a magnetic field by Pieter Zeeman [b. Zonnemaire, Netherlands, May 25, 1865, d. Amsterdam, October 9, 1943] to calculate the mass-to-charge ratio of the electron in an atom a year before electrons are discovered. *See also* 1897 PHY.

Wilhelm Wien discovers a law for black-body radiation (Wien's formula) that describes the distribution of radiation with temperature for short wavelengths but fails at longer wavelengths. This failure of Wien's formula at longer wavelengths will be one of the key problems solved by Planck's introduction of light quanta. *See also* 1884 PHY; 1900 PHY.

Transportation

Croatian inventor David Schwarz [b. 1852, d. 1897] builds the first rigid-hulled airship using an aluminum frame and sheeting for the hull and 36,800 m³ (130,000 cu ft) of hydrogen as a lifting gas. After lifting a few meters above the ground on October 8 in Berlin (Germany), it sinks from poor quality hydrogen. In a later test, however, it lifts to 400 m (1300 ft) and flies until a propeller breaks, which causes it to crash. German general Ferdinand von Zeppelin [b. Baden, Germany, July 8, 1838, d. Berlin, March 8, 1917] buys the rights to the idea for the German government. With later improve-

ments, the airship becomes known as the Zeppelin. *See also* 1884 TRAN; 1898 TRAN.

Samuel Langley tests his steam-driven, heavier-than-air flying machine on the Potomac, flying for 1.2 km (0.75 mi) before crashing. *See also* 1886 TRAN; 1897 TRAN.

Henry Ford [b. Greenfield Village, Michigan, July 30, 1863, d. Dearborn, Michigan, April 7, 1947] builds his first automobile. *See also* 1889 TRAN.

1897

★ Astronomy

George Ellery Hale sets up the Yerkes Observatory in Williams Bay, Wisconsin. The Yerkes telescope, at 1 m (40 in.), is still the largest refracting telescope on Earth.

Antonia Caetana Maury [b. Cold Spring, New York, 1866, d. 1952] refines the spectral classification of stars by using the sharpness of lines in their spectra.

Biology

Eduard Buchner [b. Munich, Germany, May 20, 1860, d. Munich, August 12, 1917] accidentally discovers that a cell-free extract of yeast, which he names zymase, can convert sugar into alcohol. This is the beginning of biochemistry; previously, chemists believed that vital processes could take place only inside living cells. *See also* 1876 MED; 1907 BIO.

Chemistry

Paul Sabatier [b. Carcassonne, France, November 5, 1854, d. Toulouse, Haute-Garonne, France, August 14, 1941] uses catalysts, such as nickel or

cobalt, to combine hydrogen with organic compounds, resulting in hydrogenated or saturated compounds. *See also* 1912 CHEM.

Adolf von Baeyer synthesizes indigo; his method will be adopted by BASF (Badische Anilin und Soda Fabrik), which starts industrial production of indigo in 1898.

Communication

Karl Ferdinand Braun [b. Fulda, Germany, June 6, 1850, d. New York, April 20, 1918] develops the modern cathode-ray display. It consists of an evacuated electron tube in which electrons, aimed by electromagnetic fields, form an image on a fluorescent screen. *See also* 1878 COMM; 1906 COMM.

Earth science

Richard Dixon Oldham [b. Dublin, Ireland, July 31, 1858, d. Llandrindod, Wales, July 15, 1936] discovers that seismic waves consist of two components: compressional waves (now called P waves) and distortional waves (S waves), as was predicted by Siméon-Denis Poisson. *See also* 1829 MATR.

Food & agriculture

C.W. Post introduces his first breakfast cereal, today called Grape Nuts, although it contains neither grapes nor nuts (Post erroneously thought that the manufacturing process resulted in grape sugar and that the cereal had a "nutty" taste). *See also* 1895 FOOD; 1904 FOOD.

Materials

Adolf Spitteler in Germany discovers, probably by accident, casein plastics, which are based on a protein in cow's milk. *See also* 1869 MATR; 1906 MATR.

Σ Mathematics

Cesare Burali-Forti [b. Arezzo, Italy, August 13, 1861, d. Turin, Italy, January 21, 1931] publishes the paradox known with his name (although discovered by Georg Cantor two years earlier): The ordinal number of the series of ordinal numbers does not appear in that series. *See also* 1895 MATH; 1899 MATH.

▼ Medicine & health

Christiaan Eijkman [b. Nijkerk, Netherlands, August 11, 1858, d. Utrecht, Netherlands, November 5, 1930] shows the relationship between the occurrence of beriberi and the consumption of polished rice, although he does not attribute the disease to the absence of a vitamin in polished rice. The role of vitamins in preventing specific diseases will be discovered in 1906. *See also* 1906 MED.

English physician Ronald Ross [b. Almora, India, May 13, 1857, d. London, September 16, 1932], after a suggestion by Patrick Manson, locates the malaria parasite in the Anopheles mosquito and determines that the mosquito transmits the parasite from one human to another. *See also* 1892 MED; 1900 MED.

Walter Bradford Cannon, American physiologist [b. Prairie du Chien, Wisconsin, October 19, 1871, d. Franklin, New Hampshire, October 1, 1945] devises the use of bismuth compounds to make soft internal organs visible on X rays.

English bacteriologist Sir Almroth Edward Wright [b. August 10, 1861, d. 1947] introduces a vaccine against typhoid. *See also* 1890 MED; 1917 MED.

Atoms have parts

Although the first notion that matter might be composed of atoms goes back to Leucippus of Miletus in the fifth century BCE, it was not until the 17th century that evidence began to accumulate that atoms really exist.

Robert Boyle, for example, believed that gases must be made of small particles to behave the way they do when compressed, reviving at least part of the theory of atoms. Atoms, as in the Greek theories, were the indivisible smallest bits of a substance.

Little progress was made in atomic theory during most of the 18th century, but in 1797 Joseph Proust stated that the ratios of one element to another are always the same in a given chemical compound. This law of definite proportions suggested to John Dalton that solids and liquids, as well as gases, must also be made of atoms. In 1803 Dalton showed that atomic theory could explain the law of definite proportions. An "atom" of a compound (what we now call a molecule) always contains a definite number of atoms of each element of which the compound is composed. In 1816 William Prout went further by explaining that atoms of elements, like "atoms" of compounds (molecules), can be made of smaller parts. Noting that the atomic masses of the known elements are close to integral multiples of hydrogen, the lightest element, Prout hypothesized that an atom of, say, oxygen, with an atomic mass of about 16, is composed of 16 hydrogen atoms. Unfortunately for Prout's theory, as new elements were discovered, many of them had atomic masses about halfway between integral multiples of the mass of hydrogen. Even so, chemists noted that about half of all then known elements had atomic masses very close to integral multiples of hydrogen, a ratio that seemed too great to be merely a coincidence.

In 1854 a series of apparently unrelated discoveries eventually unraveled the truth behind Prout's hypothesis. Heinrich Geissler found a way to make a fairly good vacuum in a glass tube. Experiments with Geissler's vacuum tubes quickly revealed that an electric current applied to the vacuum produces a glow in the glass at the other end of the tube. Apparently, electric current produces invisible rays that travel through the near vacuum. Physicists showed that the invisible rays cast sharp shadows when masks were inserted into the tube. These rays were named cathode rays in 1869, since they emerged from the electric terminal called the cathode. There was great interest in cathode rays in the latter part of the 19th century. The interest was well placed, for it led to a number of important discoveries.

Physicists were divided on what cathode rays might be. In Germany, most physicists thought that the rays might be waves, similar to electromagnetic waves. In England, where particle theories had always been popular (Newton and light, Dalton and atoms), most physicists thought that they were particles. In 1891 English physicist G. Johnstone Stoney even named the hypothetical particle: the electron.

Finally, in 1897, J.J. Thomson settled the particle-wave controversy for the next few years. After improving the vacuum, he was able to measure the deflection of the rays in an electric field, indicating to him at least that they were composed of particles. Furthermore, by measuring the amount of deflection, he was able to work out the mass of the electron, which turned out to be about 2000 times smaller than that of a hydrogen atom. Electrons were subatomic (and far too small to account for the integral ratios of atomic masses).

Since the electrons came from materials, it was quickly assumed that electrons must be parts of atoms. In 1898 Thomson proposed the "raisin-pudding" model of an atom. A sphere of positive charge is embedded with electrons, rather like raisins in a pudding. Others had different ideas. Philipp Lenard found experimental evidence that suggested that atoms are mostly empty space. As a result, he proposed in 1903 that atoms are electrons paired with similarly small positive charges in configurations that are mostly empty. In Japan, Hantaro Nagaoka stated the following year that atoms look like the planet Saturn, with rings of electrons circling a positive core.

By 1911 Ernest Rutherford and his associates had good experimental evidence that Nagaoka had come closest, but the Nagaoka model called for thousands of electrons in each atom. Other evidence showed that there could be only a few electrons. Therefore, the Rutherford model was more like the solar system than like Saturn: a central positive core, or nucleus, with a few electrons orbiting it in circles. This is the image of the atom that most people have today.

Unfortunately, nature turned out to be a lot more complicated. The Rutherford atom was not stable, and various adjustments to the model have been made over time. Furthermore, it was established that electrons are waves at the same time that they are particles. The Germans had a point after all! Today the most common picture of an atom involves cloudy regions in which electron "wavicles" (entities with characteristics of both waves and particles) may be found according to the laws of probability and quantum mechanics.

* Physics

J. J. Thomson discovers the electron, the particle that makes up electric current and the first known particle that is smaller than an atom. He and, indepen-

dently, Emil Wiechert, determine the ratio of mass to charge of the particles by deflecting them with electric and magnetic fields.

Walter Kaufmann [b. Elber-

field, Germany, 1871, d. 1947] determines the ratio of the mass to charge for cathode rays in April, about the same time that J. J. Thomson does, but Kaufmann fails to think

that the rays might be subatomic particles.

Wilhelm Wien discovers that the rays that proceed from the anode of a cathode-ray tube (canal rays) are composed of

atoms that have had electrons stripped from them in forming cathode rays; that is, the rays consist of ions. He also finds that the ions are positively charged. *See also* 1886 PHY.

Sir Jagadis Chandra Bose [b. Mymensingh, India, November 30, 1858, d. Giridih, India, November 23, 1937] demonstrates at London's Royal Institution the equipment he has invented for making and receiving microwaves, including the first waveguides and other means of collecting and focusing waves with lengths of a few millimeters. *See also* 1902 BIO.

Transportation

Clément Ader, according to his own account, on October 14 flies his steam-powered airplane *Avion III* over a distance of 300 m (960 ft), a distinct improvement over an earlier attempt with a different craft. Ader claims that better distance results from the use of

much lighter engines of 3 kg (7 lb) per hp. Most observers of the trial, however, say that *Avion III* did not fly at all or barely got off the ground. *See also* 1890 TRAN; 1901 TRAN.

Charles Parsons' *Turbinia*, the first steamship to use steam turbines for power, demonstrates its superiority over conventional steamships by unexpectedly scooting through a formal naval review in front of Queen Victoria. A conventional steam launch sent to catch *Turbinia* cannot even come close. *Turbinia* establishes a speed record at sea with 31 knots. *See also* 1894 TRAN.

1898

Archaeology

Robert Koldevey [b. Germany, 1855, d. 1925] leads a German expedition that begins an 18-year-long excavation of ancient Babylon (in Iraq). *See also* 1870 ARCH; 1922 ARCH.

Biology

Dutch botanist Martinus Willem Beijerinck [b. Amsterdam, March 16, 1851, d. Gossel, Netherlands, January 1, 1931] declares that tobacco mosaic disease is caused by an infective agent that he names a filterable virus. This is the first identification of a virus. Later this year Friedrich Löffler and Paul Frosch demonstrate that foot-and-mouth disease is also caused by a filterable virus, the first known instance of a viral disease in animals. *See also* 1892 MED; 1933 BIO.

Jules Jean-Baptiste Vincent Bordet [b. Soignes, Belgium, June 12, 1870, d. Brussels, April 6, 1961] discovers that one blood component reacts with foreign serum in a way similar to the way blood from an immunized person attacks a bacterium and that this reaction aids the immune reaction. Today this component is known as complement, a component of blood needed for antibodies to react with bacteria. *See also* 1900 MED; 1919 MED.

Edward L. Thorndike [b. Williamsburg, Massachusetts, August 31, 1874, d. August 9, 1949] shows that cats learn through a process of trial and error. He contends that experiment rather than anecdotal evidence is needed to study animal intelligence. *See also* 1883 BIO; 1904 MED.

Camillo Golgi describes the Golgi apparatus, a reticular formation in the cytoplasm of cells.

Chemistry

Marie and Pierre Curie discover polonium (Po) on July 18 and, with Gustave Bémont,

radium (Ra) on December 26. *See also* 1904 PHY; 1911 CHEM.

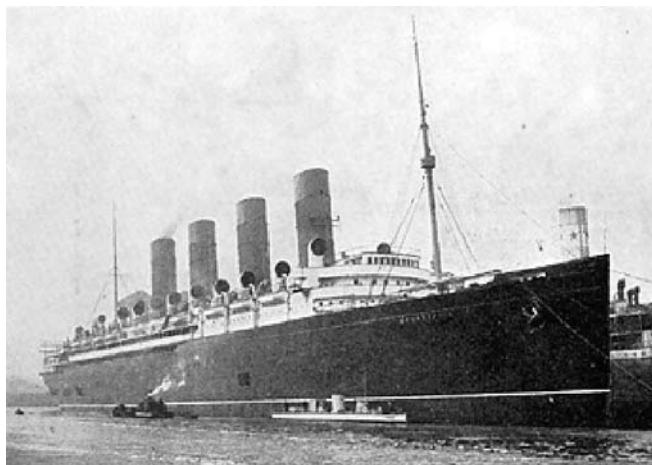
The elements krypton (Kr), neon (Ne), and xenon (Xe) are discovered by William Ramsay and Morris William Travers [b. London, January 24, 1872, d. Stroud, Gloucestershire, England, August 25, 1961]. They use fractional distillation of liquid air, gradually boiling off the nitrogen, oxygen, and argon from a large sample of liquid air. The spectrum of the remaining fraction reveals krypton. Further distillation of the argon fraction leads to the discovery of neon and finally xenon. *See also* 1904 CHEM.



Marie Skłodowska Curie

[b. Warsaw, Poland, November 7, 1867, d. Haute Savoie, France, July 4, 1934]

Curie began working with radioactivity in 1896, the year it was discovered. She coined the word *radioactivity* and developed a device to measure it. Curie was the first to discover that thorium is radioactive. She also found that some uranium ore is more radioactive than uranium itself. Marie Curie and her husband Pierre Curie demonstrated in 1898 that some of the excess radioactivity was produced by previously undiscovered elements, polonium and radium.



THE TURBINA AND THE MAURETANIA The *Turbinia*, the small ship in the foreground on the right, launched in 1897, was only 30 m (100 ft) long, but its success led the British Navy to begin using turbines almost immediately. The turbine-powered *Mauretania*, launched ten years later, was eight times as long as the *Turbinia* and displaced almost a thousand times as much water.

Communication

Valdemar Poulsen develops the Telephone, the first device to use magnetic record-

ing for data; it is an early version of a telephone answering machine. *See also* 1927 COMM.

■ Construction

The first laboratory for the study of rivers and canals is founded in Dresden, Saxony (Germany).

■ Food & agriculture

The bacteria-killing effects of X rays are noted, although no scientific work on preservation of food with radiation is pursued until the 1940s. *See also* 1906 FOOD.

❖ Materials

Johann (Hans) Goldschmidt [b. Berlin, January 18, 1861, d. Baden-Baden, Germany, May 20, 1923] develops thermite, a mixture of aluminum powder and iron or chromium that burns at a high temperature, leaving a residue of pure iron or chromium. Its most common use will be in welding. *See also* 1886 TOOL; 1901 TOOL.

Engineer Frederick Winslow Taylor, better known for his work on time-and-motion studies, and Maunsell White develop a new method of tempering steel that permits metal-cutting operations at high speed. The hardening process involves alloying steel with small amounts of tungsten, chromium, vanadium, and molybdenum. The resulting high-speed steel, or Taylor steel, keeps its cutting properties even when glowing hot, starting a revolution in the design of cutting tools. *See also* 1904 MATR.

James Dewar succeeds in liquefying hydrogen, cooling it first with liquid nitrogen, then cooling it further by expanding it through a nozzle (the

Joule-Thomson effect — a person can feel cooling from air escaping from a tire, for example). *See also* 1895 MATR; 1908 MATR.

♥ Medicine & health

On June 2 Paul-Louis Simond [b. Beaufort-sur-Gervanne, France, 1858, d. Valence, France, 1947], while fighting the plague pandemic in Bombay, India, realizes that fleas on rats transmit the disease to humans. *See also* 1894 MED.

Herta Marks Ayrton [b. Portsea, England, April 25, 1854, d. August 26, 1923], who invented a sphygmograph (an instrument for monitoring the human pulse), becomes the first woman to be elected to Britain's Institution of Electrical Engineers.

The Bayer company begins to make the synthetic morphine derivative 3,6-diacetylmorphine available under the brand name Heroin. *See also* 1832 MED.

✿ Physics

Marie and Pierre Curie discover that thorium gives off "uranium rays," a property Marie names *radioactivity*. *See also* 1903 PHY.

1899

★ Astronomy

The International Latitude Service (a.k.a. International Polar Motion Service) of the International Geodetic Association, with six stations on or near latitude 39° 8' N, is founded to observe variations in latitude caused by variations in Earth's wobble as it orbits the Sun. In the United States, this is a program of the

U.S. Coast and Geodetic Survey, with latitude observatories at Gaithersburg, Maryland, and Cincinnati, Ohio.

William Wallace Campbell [b. Hancock County, Ohio, April 11, 1862, d. San Francisco, June 14, 1938] discovers from studies with a spectroscope that Polaris (the North Star) is actually a system of three stars.

Solon Irving Bailey [b. 1854, d. 1931] discovers 85 variable stars with short periods in the globular star cluster M5. Such cluster variables, also known as RR Lyra stars after their brightest member, usually have periods of less than a day and are found throughout the Milky Way.

✿ Biology

German-American physiologist Jacques Loeb [b. Mayen, Germany, April 7, 1859, d. Hamilton, Bermuda, February 11, 1924] demonstrates parthenogenesis (reproduction without sexual union) by raising unfertilized sea urchin eggs to maturity after changing their environment. *See also* 1910 BIO.

▷ Chemistry

André-Louis Debierne [b. Paris, 1874, d. Paris, August 1949] discovers the element actinium (Ac).

Sir William Jackson Pope [b. London, October 31, 1870, d. Cambridge, England, October 17, 1939] discovers the first compound that polarizes light, or is optically active, that does not contain carbon. *See also* 1902 CHEM.

François Auguste Victor Grignard [b. Cherbourg, France, May 6, 1871, d. Lyon, France,

December 13, 1935] discovers a method for preparing magnesium alkyl halides that becomes essential in the synthesis of many organic chemicals, especially exotic ones that had previously been unknown. The chemicals involved will become known as Grignard reagents. *See also* 1912 CHEM.

☛ Communication

Guglielmo Marconi establishes the first radio link between England and France, transmitting greetings to the French scientist Edouard Branley. *See also* 1894 COMM; 1901 COMM.

⊕ Earth science

William Thomson (Lord Kelvin) in "The Age of the Earth as an Abode Fitted for Life" argues that life could evolve very quickly, so that there is no necessity for geological time to exceed 100,000,000 years. This is the length of time that Thomson in 1846 had calculated for the age of Earth based on the time it would take a hot Earth to cool. Thomas Chamberlin attacks the basic framework of these arguments. Among other flaws he notes that the Ice Age, which Thomson takes as evidence of steady cooling, was several ice ages, broken up by warmer weather. *See also* 1862 EAR; 1907 EAR.

Σ Mathematics

Georg Cantor develops a paradox (similar to Russell's Great Paradox of 1902) that suggests that there are problems with his new theory of sets. In letters dated July 28 and August 28 he considers whether the set of all cardinal numbers (including infinite ones) can also be a set. If it is,

then it has a cardinal number of its own that would be larger than all other cardinals. *See also* 1897 MATH; 1902 MATH.

David Hilbert's *Grundlagen der Geometrie* ("foundations of geometry") develops the basic concepts of geometry from undefined concepts of point, line, and plane, overcoming many logical difficulties that had surfaced in Euclid's *Elements*. *See also* 1868 MATH; 1904 MATH.

♥ Medicine & health

Physician Allvar Gullstrand [b. Landskrona, Sweden, June 5, 1862, d. Uppsala, Sweden, July 21, 1930] begins his research on corneal astigmatism. He specializes in the physics of vision and develops eyeglasses to correct astigmatism and for use after lenses have been removed in cataract operations. *See also* 1911 BIO.

⌘ Physics

British physicist Ernest Rutherford discovers that radioactivity from uranium has at least two different forms, which he calls alpha and beta rays. Rutherford also observes that alpha radiation from thorium stems from a gas, which he calls thorium emanation (known to us as radon). *See also* 1900 PHY.



David Hilbert

[b. Königsberg (Kaliningrad, Russia), January 23, 1862, d. Göttingen, Germany, February 14, 1943]

Hilbert led an ultimately unsuccessful attempt to put all mathematics on a provably consistent and finite logical basis. In 1898 Hilbert himself developed the first completely logical version of Euclidean geometry. In 1900 Hilbert proposed a famous list of 23 problems that needed solution; resolving these became one of the main threads of 20th-century mathematics. Later he contributed greatly to applied mathematical physics; the Hilbert space of vectors with infinitely many components is perhaps his most useful advance.

1900

⌘ Archaeology

Arthur John Evans [b. Nash Mills, England, July 8, 1851, d. Oxford, England, July 11, 1941] discovers the palace at Knossos, the central site of the Minoan civilization on Crete. *See also* 1908 ARCH.

Greek sponge divers accidentally stumble on the wreck of a first century BCE freighter sunk off the island of Antikythera off the southern coast of Greece while carrying works of art to Italy. Eventually they find bronze statues, glass bowls, and even a now famous bronze orrery (an astronomical instrument used for calculating positions of planets). This is the beginning of marine archaeology. *See also* 80 BCE COMP.

↗ Biology

During this single year, Hugo-Marie de Vries [b. Haarlem, Netherlands, February 16, 1848, d. Lunteren, Netherlands, May 21, 1935], Karl Franz Joseph Correns [b. Munich, Germany, September 19, 1864, d. Berlin, February 14, 1933], and Erich Tschermak von Seysenegg [b. Vienna, Austria, November 12, 1871, d. Vienna, October 11, 1962] independently rediscover Gregor Mendel's work on genetics, ignored for 40 years by science. *See also* 1865 BIO.

William Bateson coins the word *genetics* to describe the study of the physical basis of heredity.

Paul Ehrlich coins the term *receptor* to indicate sites on a molecule to which bacterial toxins or drugs will bind, causing changes to take place in cellular metabolism. *See also* 1973 MED.

Sir Frederick Gowland Hopkins [b. Eastbourne, England, June 30, 1861, d. Cambridge, England, May 16, 1947] discovers tryptophan, an amino acid. He demonstrates that it is necessary for rats to obtain it from their food, the first known essential amino acid. *See also* 1806 CHEM.



Ernest Rutherford, 1st Baron Rutherford of Nelson

[b. Brightwater, New Zealand, August 30, 1871, d. London, October 19, 1937]

Rutherford established that radioactive elements change into other elements by emitting radiation and discovered the proton. In 1911 Rutherford and coworkers became the first to envision the atom as a positive nucleus surrounded by negative electrons. In the 1920s Rutherford was the first to "smash" atoms, breaking up light atoms with alpha particles. In the 1930s he produced the first tritium (hydrogen with two neutrons) but failed to recognize it.

The discovery of genes

The monk Gregor Mendel is now famous for explaining the laws of heredity, including the roles of dominant and recessive genes and the different mathematical consequences arising from the two types of genes when sexual organisms reproduce. He worked with garden peas and looked for such traits as tall versus short or smooth seed versus wrinkled. By mating peas with different traits, he discovered such rules as, when two organisms each has one gene for a recessive trait and they are mated, approximately one-quarter of the offspring will exhibit the recessive trait. In fact, Mendel worked backward from the ratios of traits in offspring to determine the rules of inheritance.

Mendel performed his famous experiments at about the same time that Charles Darwin was explaining evolution. Darwin was already a popular author, and his ideas were soon known around the world. Mendel, however, had trouble getting published. He first sent his work to a prominent biologist who, as it happened, did not like mathematics. The biologist sent the paper back to Mendel with negative comments. In 1865 and 1869 Mendel's

work was published — by the local natural history society. After this Mendel was promoted to abbot, which kept him busy at the same time that it allowed him to grow fat. He gave up both gardening and science.

Darwin never got the chance to learn of Mendel's work, which is unfortunate, since Mendel's laws neatly fill a major gap in Darwin's theory. Darwin knew that variation occurred, but he did not know how it was inherited. Mendel's laws described the mechanism by which many traits pass from generation to generation.

In 1900, however, an astonishing coincidence put Mendel's work into the scientific mainstream. Three different biologists working in three different countries — Hugo de Vries in the Netherlands, Karl Correns in Germany, and Erich Tschermark von Seysenegg in Austria — worked out Mendel's laws for themselves. Each searched the scientific literature for prior discoveries of these laws and each somehow found the obscure papers from over 30 years before. When they published their work, they each unselfishly credited Mendel. The concept of a gene finally entered the mainstream of science.

Chemistry

Russian-American chemist Vladimir Nikolaevich Ipatieff [b. Moscow, November 21, 1867, d. Chicago, Illinois, November 29, 1952] discovers that catalysts can affect organic reactions at very high temperatures. This leads to new means for synthesizing useful chemicals, including catalytic cracking of hydrocarbons.

German physicist Friedrich Ernst Dorn [b. Guttstadt (Dobre Miasto, Poland), July 27, 1848, d. Halle, Germany, June 13, 1916] recognizes that the gas produced by thorium is a separate element, which he names nitron. Today the gas is known as radon (Rn). *See also* 1899 PHY.

Russian-American chemist Moses Gomberg [b. Elizavetgrad, Ukraine, February 8, 1866, d. Ann Arbor, Michigan, February 12, 1947] develops a

carbon compound that has one valence location open, the first known free radical. (Although free radicals form often, they are usually destroyed quickly by interacting with other compounds; Gomberg's compound is stable.)

Communication

Canadian-American physicist Reginald Aubrey Fessenden [b. Milton, Quebec, October 6, 1866, d. Hamilton, Bermuda, July 22, 1932] invents the radio-frequency alternator, the device that produces AM radio signals, although several years of development of the device will still be ahead before the alternator becomes practical. *See also* 1904 COMM.

Raoul Grimoin-Sanson [b. Elbeuf, France, 1860, d. Oissel, France, 1941] projects a motion picture on a circular screen using ten projectors. The spectators are in the mid-

dle of the circle and see a moving image all around. This idea is revived for special theaters later in the century. *See also* 1951 COMM.

Frenchman Constantin Perskyi coins the term *television*. *See also* 1884 COMM.

Earth science

Emil Wiechert [b. Tilsit, Germany, December 26, 1861, d. Göttingen, Germany, March 19, 1928] invents the pendulum seismograph, essentially the type used today. *See also* 132 CE EAR.

Energy

Edison invents the nickel-alkaline electric battery. The battery does not, however, produce nearly as much power as Edison hopes to achieve. He wants a battery that can be used in electric automobiles. *See also* 1881 ENER; 1903 ENER.

The first offshore oil wells are drilled. *See also* 1859 ENER; 1923 ENER.

Food & agriculture

Father Clément Rodier, a French missionary in Algeria, develops the hybrid of the bitter orange and the mandarin orange that is now known as the clementine.

Materials

Johann August Brinell [b. Bringetofta, Sweden, November 21, 1849, d. Stockholm, November 17, 1925] develops a test named after him for estimating metal hardness. A steel ball or diamond cone is pressed against a metal to perform the Brinell ball test, which gives the Brinell hardness number of the metal. The number is inversely proportional to the depth of impression.

Σ Mathematics

At the International Congress of Mathematicians in Paris, David Hilbert suggests 23 problems that he hopes will be solved in the 20th century; many mathematicians take Hilbert's list as an agenda, with the result that most of the problems are either solved or proved unsolvable in the century. *See also* 1934 MATH.

♥ Medicine & health

Walter Reed [b. Belroi, Virginia, September 13, 1851, d. Washington, DC, November 23, 1902] directs James Carroll [b. Woolwich, England, June 5, 1854, d. Washington, DC, September 16, 1907], Jesse William Lazear [b. Baltimore County, Maryland, May 2, 1866, d. Quemados, Cuba, September 25, 1900], and Aristides Agramonte [b. Puerto Príncipe, Cuba, June 3, 1868, d. August 19, 1931] in the study of the yellow fever epidemic in Havana. On August 27 James Carroll deliberately allows mosquitoes that have fed on yellow fever victims to bite him in his effort to prove that the disease is carried by the insects. He develops the fever but survives, only to die a few years later from yellow fever-induced heart disease. Lazear is killed by yellow fever in a successful attempt to show that it is transmitted by mosquitoes of the genus *Aedes*, as Carlos Finlay had proposed a few years earlier. *See also* 1901 MED.

Paul Ehrlich and his assistant Julius Morgenroth [b. 1871, d. 1924] make a study of hemolysis (the breakdown of red blood cells) and introduce the terms *complement* (a fraction of the blood that aids the

immune response) and *amboceptor* (a fraction that prepares bacteria for the immune system to attack them — a term no longer in use). *See also* 1898 MED; 1908 MED.

Austrian doctor Karl Landsteiner [b. Vienna, Austria, June 14, 1868, d. New York, New York, June 26, 1943] shows that there are at least three different types of human blood (A, B, and O), some of which are incompatible. The serum of a person can agglutinate red globules of a donor from an incompatible group. *See also* 1902 MED.

Sigmund Freud publishes *Die Traumdeutung* ("the interpretation of dreams"), which presents his theory that dreams are wish fulfillment. He also proposes that sexuality is an important part of childhood. *See also* 1895 MED.

Sir William Boog Leishman [b. Glasgow, Scotland, November 6, 1865, d. London, June 2, 1926] discovers the cause of a tropical disease known as kala-azar, but officially called leishmaniasis. Leishman discovers that the disease is caused by a protist spread by sandfly bites. *See also* 1880 MED.

⌘ Physics

Max Karl Ernst Ludwig Planck [b. Kiel, Germany, April 23, 1858, d. Göttingen, West Germany, October 3, 1947] announces the first step toward quantum theory on December 14; substances can only emit light at certain energies, which implies that some physical processes are not continuous, but occur only in specified amounts called quanta. *See also* 1905 PHY.

Henri Becquerel discovers that

part of the radiation produced by uranium (and identified as beta rays by Ernest Rutherford) is identical to the electrons identified in cathode-ray experiments. *See also* 1899 PHY.

Paul Villard [b. Lyon, France, September 28, 1860, d. Bayonne, Basses-Pyrénées, France, January 13, 1934] is the first to observe a radiation emitted by radium that is more penetrating than X rays. This third type of radioactivity is now called gamma radiation and is recognized as high-energy electromagnetic waves. *See also* 1914 PHY.

Hans Friedrich Geitel [b. Braunschweig, Germany, July 16, 1855, d. Wolfenbuttel, Germany, August 15, 1923] and Charles Wilson independently study the spontaneous discharge of electric charge on objects caused by natural radioactivity. In the process, each discovers that there is a hitherto unknown factor causing discharge, which is later identified as cosmic radiation. *See also* 1912 AST.

Paul Karl Ludwig Drude [b. Brunswick, Germany, July 12, 1863, d. Berlin, July 5, 1906] publishes *Lehrbuch der Optik* ("handbook of optics") arguing in favor of Maxwell's electromagnetic theory. He also becomes the first to show that conduction of electricity in metals results from a few electrons that are free to move away from their atoms. *See also* 1928 PHY.

█ Tools

Nikola Tesla proposes the use of radio waves to detect moving objects. Tesla's proposal is the basic idea of radar, but the technology is not sufficiently

developed for making this idea practical. The short radio waves called microwaves, needed to locate an object with any precision, could not yet be generated. *See also* 1904 TOOL.

↗ Transportation

In Germany, Count Ferdinand von Zeppelin [b. Konstanz, Germany, July 8, 1838, d. Charlottenburg, Germany, March 8, 1917] launches on July 2 the first of his line of rigid-framed, hydrogen-filled airships, which come to be known as Zeppelins. These are built at a rapid pace during World War I, but after 1918 the main stock will be taken away by the Allied victors in the war. By 1924 the Zeppelin company will be back in operation in Germany, however. *See also* 1896 TRAN; 1937 TRAN.

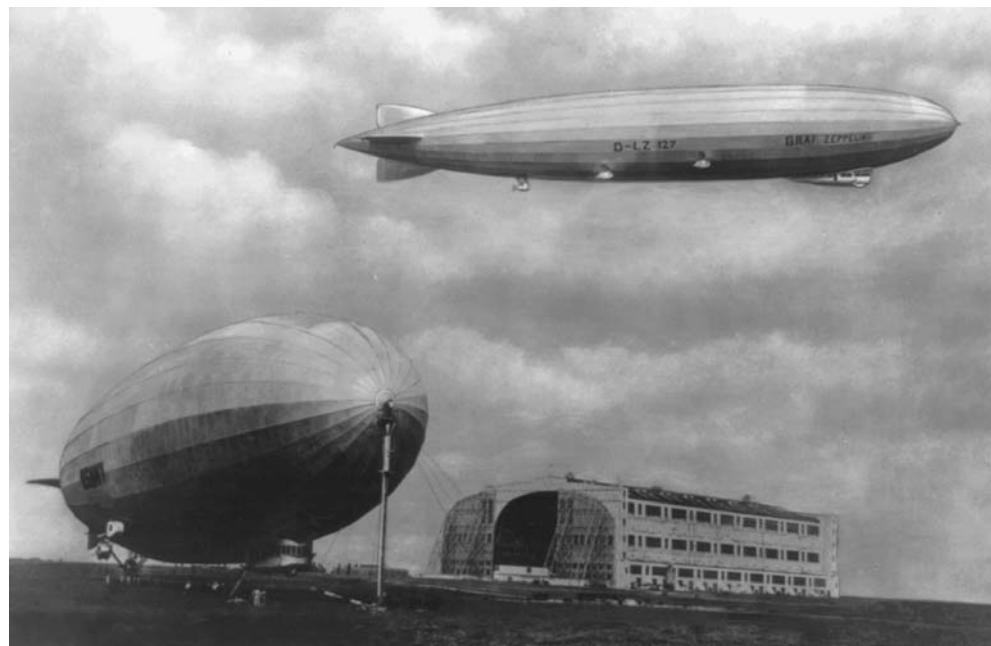
1901

↗ Biology

Jokichi Takamine [b. Takaoka, Japan, November 3, 1854, d. New York, New York, July 22, 1922] discovers adrenaline (epinephrine) and synthesizes it. Thomas Bell Aldrich [b. 1861, d. 1939] independently makes the same discovery.

The okapi, a relative of the giraffe, is discovered in Africa. It is the last large land mammal to become known to science for several decades, until large goats and antelopes will be discovered in the forests of Vietnam in the 1990s. *See also* 1993 BIO.

Hugo de Vries' *Die Mutationstheorie* ("the mutation theory") introduces the idea that changes in species occur in jumps, which he calls "mutations." Volume 1 is published this year and volume 2 in 1903.



GRAF ZEPPELIN ALOFT AND MOORED U.S. NAVY DIRIGIBLE Few today recall the United States purchased a Zeppelin dirigible from Germany in 1923, the *Los Angeles*, moored here in Lakehurst, New Jersey, while the better known *Graf Zeppelin* floats overhead. The *Graf Zeppelin*, built in 1928, gained its fame by circumnavigating Earth in 12 days 11 hours with a full load of passengers. The *Los Angeles*, briefly decommissioned in 1932, was on active duty until 1940.

Chemistry

Eugène Demarçay [b. Paris, January 1, 1852, d. Paris, 1904] discovers the chemical element europium (Eu).

Jacobus Van't Hoff of the Netherlands wins the Nobel Prize in chemistry for his discovery of the law of chemical dynamics of weak solutions. *See also* 1885 CHEM.

Communication

Guglielmo Marconi receives the letter S in St. John's, Newfoundland. It has been transmitted from England, the first transatlantic telegraphic radio transmission. *See also* 1899 COMM.

Herman Hollerith develops the first numerical keyboard for punching cards for tabu-

lating machines. *See also* 1820 COMP.

Donald Murray from New Zealand invents a new five-unit code that eventually becomes the basis for telex (starting around 1930), a method for communicating between two teletypewriters over telephone lines. *See also* 1874 COMM.

Karl Braun uses a crystal detector for the detection of radio waves. *See also* 1897 COMM; 1906 ELEC.

Reginald Fessenden discovers the heterodyne principle: When two radio signals are mixed in a receiver, a third signal with a frequency equal to the difference in frequency of the two received signals is created. This principle will be at

the base of the superheterodyne receiver developed by Edwin Armstrong. *See also* 1918 COMM.

General Electric is the first company in the United States to open a research laboratory. *See also* 1876 COMM; 1902 COMM.

Sir Edward Richard Henry [b. London, July 26, 1850, d. February 19, 1931], who had used fingerprints in India, establishes a system of fingerprint classification for the British police that continues (with improvements) to be used in English-speaking countries. A different system, developed shortly before this time by Juan Vucetich in Argentina, will be used in Spanish-speaking countries. *See also* 1880 COMM; 1987 BIO.

On December 10 the first Nobel Prizes are awarded pursuant to the will of Alfred Bernhard Nobel, who had left the money for prizes for peace, literature, physics, and physiology or medicine on his death five years previously.

Earth science

Johann Elster and Hans Geitel demonstrate that radioactivity is found in rocks, springs, and air. *See also* 1900 PHY.

Energy

Nils Gustaf Dalén [b. Stenstorp, Sweden, November 30, 1869, d. Stockholm, December 9, 1937] begins work on a system that combines a device (the sun valve) that determines whether it is light or dark outside with stored acetylene gas to automatically turn the lights of lighthouses on and off. The combination permits lighthouses to function unattended for periods of up to a year. *See also* 1912 ENER.

Peter Cooper Hewitt [b. New York, May 5, 1861, d. Neuilly-sur-Seine, France, August 25, 1921] begins to market a mercury vapor lamp, having partially solved the main problem with the lamp, that its spectrum contains no red. Cooper Hewitt uses a fluorescent screen that converts some of the excess blue, green, and yellow light into red. The first practical installation of the Cooper Hewitt lamp is in 1903. *See also* 1892 ENER; 1933 ENER.

Hermann Walther Nernst [b. Breisen, West Prussia, June 25, 1864, d. Bad Muskau, Germany, November 18, 1941] patents a form of incandescent lamp that uses a filament consisting of oxides of rare earths. It is introduced commercially but does not have

wide use. Nevertheless, the “Nernst glower” spurs activity toward the development of more practical filaments than carbon. *See also* 1879 ENER.

Food & agriculture

Charles W. Hart [b. Charles City, Iowa, 1872, d. Missoula, Montana, 1937] and Charles H. Parr start building and marketing the Hart-Parr internal combustion engine tractor. It is the first commercially successful gasoline tractor, selling 200 by 1906. *See also* 1881 FOOD.

Medicine & health

Adolf Windaus [b. Berlin, December 25, 1876, d. Göttingen, Germany, July 9, 1959] shows that the molecule of vitamin D can be affected by sunlight. *See also* 1923 MED.

Eugene L. Opie [b. Staunton, Virginia, July 5, 1873, d. March 12, 1971] discovers the relationship of abnormalities in cells in the pancreas called the islets of Langerhans to diabetes mellitus.

Walter Reed establishes that a virus causes yellow fever. He had shown that the disease was carried by mosquitoes the previous year. *See also* 1900 MED.

Dutch physician Gerrit Grijns [b. 1865, d. 1944] shows that beriberi is caused by the removal of a nutrient from rice during polishing. *See also* 1897 MED; 1912 BIO.

Sigmund Freud’s *Zur Psychopathologie des Alltags* (“the psychopathology of everyday life”) introduces the famous concept of the “Freudian slip.”

Havelock Ellis [b. Croydon, England, February 2, 1859, d. 1939] starts his *Studies in the Psychology of Sex*; the sixth

and last volume will be published in 1910.

Emil von Behring of Germany wins the Nobel Prize for physiology or medicine for his discovery of diphtheria antitoxin. *See also* 1890 MED.

Physics

Piotr Nicolaievich Lebedev [b. Moscow, March 8, 1866, d. Moscow, April 1, 1912] measures the radiation pressure of light, confirming Maxwell’s theory of electromagnetism. This is independently observed by Ernest Fox Nichols [b. Leavenworth, Kansas, 1869, d. 1924] and Gordon F. Hull.

Ernest Rutherford and Frederick Soddy [b. Eastbourne, England, September 2, 1877, d. Brighton, Sussex, England, September 22, 1956] discover that thorium left to itself changes into another form (another element, in fact; however, they do not realize at the time that thorium is changing into an isotope of radium).

Wilhelm Roentgen of Germany wins the Nobel Prize in physics for his discovery of X rays. *See also* 1895 PHY.

Tools

King Camp Gillette [b. Fond du Lac, Wisconsin, January 5, 1855, d. Los Angeles, July 9, 1932] and William Nickerson patent the first safety razor. *See also* 1903 TOOL.

Welding using oxygen and acetylene is introduced. *See also* 1898 MATR.

After observing a machine that blows dust away, English engineer Hubert Cecil Booth [b. Gloucester, England, 1871, d. 1955] develops the first successful vacuum cleaner, a complex and unwieldy machine

driven by a 5-hp engine and mounted on a horse-drawn cart. Booth’s Vacuum Cleaner Company begins advertising in February 1902. Its success is ensured after it is used to clean up from the rehearsal for the coronation of Edward VII, leading to the purchase of the first two models, one for Buckingham Palace and one for Windsor Castle. *See also* 1893 TOOL.

Transportation

The Wright brothers, Wilbur [b. Millville, Indiana, April 16, 1867, d. Dayton, Ohio, May 30, 1912] and Orville [b. Dayton, Ohio, August 19, 1871, d. Dayton, January 30, 1948] fly their first glider, reaching distances as much as 183 m (600 ft). *See also* 1900 TRAN; 1903 TRAN.

1902

Archaeology

A French expedition at Susa (in Iran), the ancient capital of Elam, discovers tablets engraved with the code of Hammurabi, the first known set of laws.

Biology

Walter Stanborough Sutton [b. Utica, New York, April 5, 1877, d. March 10, 1916] states that chromosomes are paired and may be the carriers of heredity. *See also* 1895 BIO; 1903 BIO.

Clarence Erwin McClung [b. Clayton, California, April 5, 1870, d. Swarthmore, Pennsylvania, January 17, 1946] observes that grasshoppers have two types of sperm, one that produces males and one females. Studying the sperm leads him to suspect that chro-

mosomes are involved in determining sex. *See also* 1905 BIO.

William Maddock Bayliss [b. Wolverhampton, England, May 2, 1860, d. London, August 27, 1924] and Ernest Henry Starling [b. London, April 17, 1861, d. at sea near Kingston, Jamaica, May 2, 1927] discover secretin, a hormone released by the walls of the small intestines that controls the pancreas. They establish the role of hormones in the body. *See also* 1775 MED; 1905 BIO.

Sir Jagadis Chandra Bose, who has used his training in physics to develop instruments for studying plant growth and other extremely small motions of plants, publishes *Response in the Living and Non-Living* which describes his use of electricity with plants. *See also* 1897 PHY.

Chemistry

William Pope develops optically active compounds based on sulfur, selenium, and tin. *See also* 1899 CHEM.

Emil Fischer of Germany wins the Nobel Prize in chemistry for sugar and purine synthesis. *See also* 1887 CHEM.

Communication

German physicist Arthur Korn [b. May 20, 1870, d. 1945] develops a method of transmitting photographs over wires by electricity, breaking the image down into components and then reconstructing it at the other end using selenium cells. The resulting fax process, then known as telephotography, soon becomes indispensable for transmitting photographs of news events. *See also* 1904 COMM.

The first electric typewriter to be sold worldwide is produced, the Blickensderfer Electric, invented by George Canfield Blickensderfer [b. Erie, Pennsylvania, 1850, d. Stamford, Connecticut, August 15, 1917] of Stamford, Connecticut. *See also* 1895 COMM.

Gugliemo Marconi develops the magnetic detector for radio, an improved way of detecting signals that replaces the coherer. *See also* 1890 COMM.

In November Reginald Fessenden and partners form the National Electric Signaling company (known as NESCO), the first operator of commercial wireless telegraphy stations over land, with base stations in Collingswood, New Jersey, Jersey City, New Jersey, and Washington, DC. *See also* 1900 COMM; 1904 COMM.

Following the example of General Electric, Du Pont Company and Parke-Davis both establish research departments. *See also* 1901 COMM; 1911 COMM.

Earth science

Leon Teisserenc de Bort [b. Paris, November 5, 1855, d. Cannes, Alpes-Maritimes, France, January 2, 1913] is the first to discover that Earth's atmosphere has at least two different layers, which he names the troposphere and the stratosphere.

British-American electrical engineer Arthur Edwin Kennelly [b. Bombay, India, December 17, 1861, d. Boston, Massachusetts, June 18, 1939] discovers that there is a layer of electrically charged particles in the upper atmosphere that reflects radio waves, independently discovered by Oliv-

er Heaviside a few months later. This layer later will become known as the ionosphere. *See also* 1882 EAR.

Mount Pelée on Martinique erupts, killing almost all of the 38,000 people in Saint Pierre. Legend has it that one prisoner lived through the deadly cloud of hot gases that flowed from the volcano, although later research suggests that two people survived, instead of just one. *See also* 1883 EAR.

Ecology & the environment

Danish physiologist Schack August Steenberg Krogh [b. Gronå, Denmark, November 15, 1874, d. Copenhagen, September 13, 1949] demonstrates that ocean waters have a role in buffering carbon dioxide in the atmosphere, a result that will later be seen as important in the question of global warming. *See also* 1859 ECOL; 1905 ECOL.

Energy

Robert Bosch [b. Albeck, Germany, September 23, 1861, d. Stuttgart, Germany, March 12, 1942] invents the spark plug. *See also* 1893 ENER.

Materials

Arthur D. Little [b. Boston, Massachusetts, December 15, 1863, d. August 1, 1935], William Hultz Walker [b. Pittsburgh, Pennsylvania, April 7, 1869, d. Pasadena, California, 1934], and Harry S. Mork obtain the first U.S. patent for an artificial fiber, a form of yarn for spinning based on the acetate process for rayon. *See also* 1884 MATR; 1940 MATR.

Mathematics

English mathematician and philosopher Bertrand Arthur

William Russell, 3rd Earl Russell [b. Trelleck, England, May 18, 1872, d. Penrhynedraeth, Merionethshire, England, February 2, 1970] discovers his "Great Paradox" concerning the set of all sets that do not contain themselves. This set either contains itself or it doesn't, but if it does, then it doesn't and vice versa. This paradox undermines the foundations of Gottlob Frege's and Russell's attempts to base mathematics on logic. *See also* 1899 MATH.

Henri Léon Lebesgue [b. Beauvais, Oise, France, June 28, 1875, d. Paris, July 26, 1941] introduces a new method of integration that allows the integration of functions over domains not possible by the Riemann method. It will be known as Lebesgue integration. *See also* 1854 MATH.

Beppo Levi [b. Turin, Italy, May 14, 1875, d. Rosario, Argentina, August 28, 1961] makes the first explicit statement of the axiom of choice: One can choose exactly one element from any given collection of disjoint nonempty sets. This axiom eventually separates mathematics into two types, one that accepts it and one that rejects it. *See also* 1883 MATH; 1904 MATH.

Medicine & health

American surgeon and author Harvey William Cushing [b. Cleveland, Ohio, April 8, 1869, d. New Haven, Connecticut, October 7, 1939] investigates the pituitary gland. *See also* 1926 BIO.

Karl Landsteiner discovers a fourth blood group, AB. *See also* 1900 MED; 1930 MED.

Charles Robert Richet [b. Paris, August 26, 1850, d. Paris, December 3, 1935] coins the

term *anaphylaxis* ("overprotection") to describe the phenomenon he has discovered, which is that a second exposure to a substance can provoke shock. At this point the concept of allergy is not clear (the word *allergy* will not be coined until 1906). Today physicians recognize anaphylaxis as the body's overreaction to an allergen. *See also* 1913 MED.

Sir Ronald Ross of England wins the Nobel Prize for physiology or medicine for his work on malaria infections. *See also* 1897 MED.

Physics

Philipp von Lenard discovers that the energy of electrons produced when zinc is exposed to ultraviolet light is a function of the wavelength of the light and not of the intensity. This photoemissive effect, whose energy distribution cannot be explained by the wave theory of light, will be explained by Einstein in a famous paper that first introduces wave-particle duality to physics. *See also* 1899 PHY; 1905 PHY.

Owen Willans Richardson [b. Dewsbury, England, April 26, 1879, d. Alton, Hampshire, England, February 15, 1959] tries to refract X rays with the edge of a Gillette safety razor blade. His failure to observe refractions tends to confirm an (incorrect) theory that X rays are a beam of neutral particles. Had he used a crystal, he would have discovered X-ray diffraction. *See also* 1912 PHY.

Ernest Rutherford and Frederick Soddy publish the paper "The Cause and Nature of Radioactivity," which sets forth the atomic disintegration theory of radioactivity. Their explanation recognizes

that radioactive elements change into other elements as they release particles. *See also* 1901 PHY; 1904 PHY.

J. Willard Gibbs's *Elementary Principles in Statistical Mechanics* is published, providing a mathematical framework that will be used for quantum theory. It also gives other ideas from statistical mechanics a firm mathematical foundation.

Hendrik Lorentz and Pieter Zeeman of the Netherlands win the Nobel Prize in physics for their discovery of the effect of magnetism on electromagnetic radiation. *See also* 1896 PHY.

I Tools

Richard Adolf Zsigmondy [b. Vienna, Austria, April 1, 1865, d. Göttingen, Germany, September 23, 1929] invents the ultramicroscope, a device for seeing the small particles in a colloidal solution. *See also* 1903 TOOL.

Willis H. Carrier [b. Angola, New York, November 26, 1876, d. October 7, 1950] invents the first air conditioner. It is developed for use in a printing plant to maintain conditions under which ink dries evenly. *See also* 1881 ENER; 1903 TOOL.

→ Transportation

In France, Louis Renault [b. Paris, February 12, 1877, d. Paris, October 24, 1944] develops the drum brake. In Great Britain, Frederick Lanchester invents the disk brake, which has better heat dissipation properties than the drum brake. First used on airplanes, the use of disk brakes on automobiles will become common only during the 1970s. *See also* 1867 TRAN; 1919 TRAN.

John Wilkinson designs the first air-cooled engine to be used in an automobile, the 1902 Franklin, built in Syracuse, New York. The engine, without the conventional water-cooled automobile radiator, is much lighter than other automobile engines of the day. The first Franklin also uses wooden frames and aluminum parts for lightness; the entire car weighs about 500 kg (1000 lb). Franklin automobiles will continue to be produced until 1929.

1903

↗ Biology

Ivan Pavlov reports his experiments in learning by conditioning. He demonstrates that a dog trained by giving it food at the same time a bell is rung will soon learn to salivate at the sound of the bell with no food present. *See also* 1895 BIO.

Svante Arrhenius suggests that single spores of living organisms may travel across solar systems propelled by solar light.

Walter Sutton's *The Chromosomes in Heredity* contains detailed studies that support his proposal of the previous year that genes are carried by the chromosomes. He argues that each egg or sperm cell contains only one of each chromosome pair, which accounts for the random factor in heredity. *See also* 1902 BIO.

▷ Chemistry

Svante Arrhenius of Sweden wins the Nobel Prize in chemistry for his theory of ionic dissociation. *See also* 1884 CHEM.

↳ Communication

African-American inventor Frederic Eugene Ives [b. Litchfield, Connecticut, 1856, d.

1937] patents a parallax-based stereographic process for producing three-dimensional images. *See also* 1893 COMM.

■ Construction

The distinctive Flatiron Building (so named because of its triangular cross-section) is constructed in New York City. At 69 m (226 ft), it is often considered the first skyscraper in New York City. Higher buildings have been built before this, however, in Chicago, Illinois, the original home of the skyscraper. *See also* 1889 CONS; 1913 CONS.

The Ingals Building in Cincinnati, Ohio, is the first office building built with reinforced concrete. *See also* 1889 MATR.

▼ Energy

Giovanni Conti builds in Larderello, Italy, the first geothermal electric power station, supplying power to four light bulbs. A 290-megawatt geothermal station will be completed at Larderello more than 50 years later, supplying electricity to the Italian railroads. *See also* 1960 ENER.

Edison opens a plant to make an improved version of his nickel-alkaline electric battery, but when the battery goes on sale in 1904, it is so unreliable that Edison soon recalls it and halts manufacture while he tackles the problem again in the laboratory. *See also* 1900 ENER; 1908 ENER.

■ Food & agriculture

German coffee merchant Ludwig Roselius, searching for a way to decaffeinate coffee, finds accidentally that coffee beans soaked in seawater can be used to produce acceptable flavor in coffee with 97 percent of the caffeine removed.

He names his product Sanka for *sans caffeine*. *See also* 1908 FOOD.

Σ Mathematics

Gottlob Frege's *Grundgesetze der Arithmetik* ("basic laws of arithmetic") is the first attempt to derive the laws of mathematics from formal logic, but it is flawed by its failure to account for Bertrand Russell's "Great Paradox" of 1901, sent to Frege just as he was finishing the second volume of his book. *See also* 1902 MATH.

Bertrand Russell's *The Principles of Mathematics* is an outline of a program to find an axiomatic foundation to mathematics by basing mathematics on pure logic. *See also* 1902 MATH; 1910 MATH.

▼ Medicine & health

Dutch physiologist Willem Einthoven [b. Semarang, Java, May 22, 1860, d. Leiden, Netherlands, September 29, 1927] develops in the Netherlands the string galvanometer, the forerunner of the electrocardiograph, used to measure tiny electrical currents produced by the heart. *See also* 1880 TOOL; 1924 MED.

Surgeon Georg Clemens Perthes [b. Mörs, Germany, September 17, 1869, d. Arosa, Switzerland, January 3, 1927] discovers that X rays inhibit the growth of tumors and proposes X-ray treatment for cancer. *See also* 1895 PHY.

Niels Finsen of Denmark wins the Nobel Prize for physiology or medicine for his treatment of skin disease with light. *See also* 1893 MED.

⊗ Physics

Henri Poincaré recognizes that very small inaccuracies in ini-

tial conditions can lead to vast differences in a short order, the fundamental idea of chaos (which will not be explored much further until the 1970s and 1980s). *See also* 1961 EAR.

Ernst Mach's *Geschichte der Mechanik* ("history of mechanics"), which criticizes absolute space and absolute time in Newtonian mechanics, profoundly influences Einstein. *See also* 1887 PHY; 1905 PHY.

Ernest Rutherford continues his study of radioactivity. He shows that a strong magnetic field can deflect alpha particles in the opposite direction from beta rays (electrons), meaning that alpha particles are positively charged. He names the third kind of radioactivity *gamma rays*. *See also* 1900 PHY; 1904 PHY.

On August 13 William Ramsay and Frederick Soddy announce that helium is formed by the radioactive decay of radium. Specifically, alpha particles are the nuclei of helium atoms, although Ramsay and Soddy do not know this at the time. *See also* 1908 PHY.

Henri Becquerel, Pierre Curie, and Marie Curie of France share the Nobel Prize for physics; Becquerel for his discovery of natural radioactivity and the Curies for their study of radioactivity. *See also* 1896 PHY; 1898 PHY.

I Tools

Willis Carrier builds the first whole-building air conditioner for a manufacturing plant in Brooklyn, New York. *See also* 1902 TOOL; 1906 TOOL.

The safety razor, first thought of by King Gillette in 1895 and under development since,

goes on sale, selling a total of 51 razors and 168 blades during its first year. By 1904, however, sales of blades will be up to 123,648.

William Crookes invents the spintharoscope, a magnified fluorescent surface that can detect individual alpha particles. *See also* 1902 TOOL.

→ Transportation

The first successful airplane is launched at Kitty Hawk by Wilbur and Orville Wright on December 17. Powered by an internal combustion engine of 9 kW (12 hp), its best flight of the day lasts 59 seconds. *See also* 1901 TRAN; 1905 TRAN.

Konstantin Tsiolkovsky proposes that liquid oxygen be used for powering rocket engines for space travel. He also suggests the use of multi-stage rockets in which stages that have exhausted their fuel are discarded to decrease weight during the escape from Earth's gravity. Like Hermann Ganswindt in 1881, but independently, Tsiolkovsky calculates that the speed required to escape Earth's gravity, known as the *escape velocity*, is 40,232 km/h (25,000 mph). *See also* 1892 TRAN; 1914 TRAN.

1904

★ Astronomy

Jacobus Cornelius Kapteyn [b. Barneveld, Netherlands, January 19, 1851, d. Amsterdam, Netherlands, June 18, 1922] discovers that proper motions of stars are not random, but that there are two distinct star streams in the galaxy, traveling in opposite directions. Further research by other astronomers will show that this effect is caused by rotation of the

galaxy, which had not been suspected previously. *See also* 1927 AST.

Johannes Franz Hartmann [b. Erfurt, Germany, January 11, 1865, d. Göttingen, Germany, September 13, 1936] reports the discovery of the stationary calcium lines in the spectrum of the binary Delta Orionis caused by the presence of an interstellar cloud of atoms. This is the first discovery of interstellar matter.

George Ellery Hale sets up the Mount Wilson Observatory in California, and construction starts on the Mount Wilson 2.5 m (100-inch) telescope. *See also* 1908 AST.

↗ Biology

Sir Arthur Harden [b. Manchester, England, October 12, 1865, d. Bourne End, Buckinghamshire, England, June 17, 1940] discovers the first coenzyme, a compound that is not a protein but that is required for the protein to act as an enzyme. *See also* 1905 BIO.

Hans Karl von Euler-Chelpin of Sweden [b. Augsburg, Germany, February 15, 1873, d. Stockholm, Sweden, November 7, 1964] studies the action of enzymes in relation to catalysis. *See also* 1929 BIO.

Blood Immunity and Blood Relationship by George Henry Falkiner Nuttall [b. San Francisco, July 5, 1862, d. London, December 16, 1937] shows that phyla, classes, orders, and genera of organisms can be distinguished by serological methods; that is, by examining the proteins in the organisms' blood.

Ivan Pavlov of Russia wins the Nobel Prize for physiology or medicine for his study of the

physiology of digestion. *See also* 1895 BIO.

↑ Chemistry

Richard Wilhelm Heinrich Abegg, German chemist [b. Danzig (Gdansk, Poland), January 9, 1869, d. Koszalin (Koszalin, Poland), April 3, 1910], suggests that the outer electron shell governs the chemical properties of an atom. Noting that the inert gases (neon, argon, krypton, xenon, and radon) all have eight electrons and are especially stable, he proposes what comes to be called Abegg's rule: that the difference of the maximum positive and negative valence of an element tends to be eight. *See also* 1916 CHEM.

Frederick Stanley Kipping [b. Manchester, England, August 16, 1863, d. Criccieth, Caernarvonshire, Wales, May 1, 1949] discovers silicones, a class of polymers that because of their stability, ability to repel water, slipperiness, and lack of reaction with living tissues become important in many applications, notably in prosthetic devices such as artificial ear lobes and breasts.

Sir William Ramsay of England wins the Nobel Prize in chemistry for his discovery of inert gas elements and their placement in the periodic table. *See also* 1898 CHEM.

↳ Communication

Ira Washington Rubel in New York accidentally invents offset printing about this time when he observes that a rubber pad can transmit an image from a lithographic plate to paper.

L.C. Smith & Bros. introduces a replacement for its Smith Premier typewriter, one that has a shift to produce capital

letters. The original Smith Premier (date uncertain) uses two keyboards, one for capital letters and another for lowercase. *See also* 1872 COMM.

Reginald Fessenden demonstrates the transmission of speech by the modulation of a radio wave generated by his high-frequency alternator. The water-cooled microphone is connected directly to the transmitting circuit. More satisfactory results, however, will be obtained a few years later with continuous-wave transmitters using vacuum tube oscillators. *See also* 1900 COMM; 1906 COMM.

American Alphons Van der Grinten develops a method for the map of Earth in which countries near the North and South Pole are represented more to their true size than the Mercator projection. *See also* 1568 COMM.

Charles Guillaume discovers that a kilogram of water has a volume of 1000.028 cm^3 at 4°C , not 1000 cm^3 as planned by the designers of the metric system. Since this is also the definition of a liter, the liter is redefined as being 1000.028 cm^3 .

Earth science

Weather Forecasting as a Problem in Mechanics and Physics by Vilhelm Frimann Koren Bjerknes [b. Oslo, Norway, March 14, 1862, d. Oslo, April 9, 1951] is one of the first scientific studies of weather forecasting. *See also* 1918 EAR.

Electronics

John Ambrose Fleming [b. Lancaster, England, November 29, 1849, d. Sidmouth, England, April 18, 1945] files a patent for the first vacuum tube. Also called the "Fleming

valve," it is a diode that acts as a rectifier, a device that makes current flow in a single direction instead of alternating back and forth; hence, it changes alternating current (a.c.) to direct current (d.c.). *See also* 1883 PHY; 1907 COMM.

Energy

Ultraviolet lamps are introduced.

Johann Phillip Ludwig Elster [b. Bad Blankenburg, Germany, December 24, 1854, d. Bad Harzburg, Saxony, Germany, April 6, 1920] and Hans Geitel devise the first practical photoelectric cell, although their earliest models go back to 1896. In a photoelectric cell, electrons are emitted when the cell is struck by light. *See also* 1888 ELEC; 1905 PHY.

Willis R. Whitney [b. Jamestown, New York, August 22, 1868, d. Schenectady, New York, January 9, 1958] invents a metalized heat-treated carbon filament for light bulbs that leads to the development of the tungsten filament, which continues in use to this day. Tungsten lasts longer than other materials because of its high melting point of 3400°C . *See also* 1880 ENER.

Food & agriculture

C.W. Post calls his new brand of corn flakes "Elijah's Manna" at first, but finds that Christian ministers oppose it under that name. He renames the cereal "Post Toasties." *See also* 1897 FOOD.

Materials

Leon Guillet [b. St. Nazaire, France, July 11, 1873, d. Paris, May 9, 1946] develops the first stainless steels, but unaccountably fails to note that

they resist corrosion. *See also* 1898 MATR; 1911 MATR.

W.C. Parkin in France develops a nonflammable celluloid by adding a soluble metallic salt to ordinary celluloid. *See also* 1862 BIO; 1918 MED.

Mathematics

David Hilbert develops a model for his rigorous version of Euclidean geometry within the system of arithmetic, demonstrating that if there are no contradictions in arithmetic, then there are also none in geometry. *See also* 1899 MATH.

Ernst Zermelo proves that every set can be well ordered (that is, has only subsets with first members), but in the process uses the axiom of choice, which engenders great criticism by fellow mathematicians. It will later be determined that the well-ordered set theorem is equivalent to the axiom of choice, so that both must be accepted or rejected together. *See also* 1883 MATH; 1938 MATH.

Medicine & health

Army surgeon William Crawford Gorgas [b. Mobile, Alabama, October 3, 1854, d. London, July 3, 1920] is put in charge of disease control during the building of the Panama Canal. He develops such effective measures for controlling mosquitoes that both malaria and yellow fever are wiped out in the region around the canal. *See also* 1914 TRAN.

Together with Christian Bohr, Schack August Steenberg Krogh, Danish physiologist, publishes a work demonstrating that carbon dioxide reduces the capacity of hemoglobin to bind oxygen. This is

the first explanation of how the blood transports and releases oxygen to tissues. The discovery becomes known as the Bohr effect. *See also* 1862 BIO; 1918 MED.

Edward L. Thorndike introduces statistics as an objective tool in psychological research. *See also* 1898 BIO.

Physics

Ernest Rutherford's *Radioactivity* is published. It describes nuclear radiation in terms of alpha, beta, and gamma rays and reports his discovery that radioactivity is caused by the transformation of one element into another. *See also* 1903 PHY; 1908 CHEM.

J.J. Thomson's "On the Structure of the Atom" proposes the "plum-pudding model" of the atom, in which the electrons are embedded in a sphere of positive electricity. A different idea appears in "Kinetics of a System of Particles Illustrating the Line and Band Spectrum and the Phenomena of Radioactivity" by Hantaro Nagaoka [b. Nagasaki, Japan, August 15, 1865, d. Tokyo, December 11, 1950], which includes Nagaoka's "Saturnian model" of the atom, in which a positive nucleus is surrounded by a ring of thousands of electrons. *See also* 1913 PHY.

Bertram Borden Boltwood [b. Amherst, Massachusetts, July 27, 1870, d. Hancock Point, Maine, August 15, 1927], Herbert McCoy [b. 1870, d. 1945], and Robert Strutt independently discover that radium is a decay product of uranium. *See also* 1898 PHY.

Hendrik Lorentz anticipates relativity in a paper by introducing the notion of "corresponding states," although he

maintains that there is an ether. *See also* 1905 PHY.

Charles Glover Barkla [b. Widnes, England, June 27, 1877, d. Edinburgh, Scotland, October 23, 1944] discovers that X rays are transverse waves, like those of light, and not longitudinal waves, as had been previously thought. *See also* 1895 PHY; 1917 PHY.

Ludwig Prandtl [b. Freising, Germany, February 4, 1875, d. Göttingen, Germany, August 15, 1953] discovers a flowing liquid in a tube has a thin boundary layer adjacent to the walls of the tube that does not flow as fast as the rest of the liquid.

Lord Rayleigh of England wins the Nobel Prize for physics for his discovery of argon. *See also* 1892 CHEM.

I Tools

Reginald Fessenden develops a depth finder (fathometer) that uses electromagnetic waves. *See also* 1900 TOOL; 1938 TOOL.

Christian Hülsmeyer in Düsseldorf patents a detection system based on reflected radio waves, an early version of radar. *See also* 1900 TOOL; 1931 TOOL.

↗ Transportation

Benjamin Holt [b. 1849, d. 1920] designs the modern tracked vehicle. *See also* 1908 FOOD.

The Trans-Siberian Railway, started in 1891, is completed in Russia; it links Moscow to Vladivostok.

1905

★ Astronomy

Ejnar Hertzsprung [b. Frederiksberg, Denmark, October 8,

1873, d. Roskilde, Denmark, October 21, 1967] is the first to note that there is a relationship between color and luminosity of stars, but his work is not well known. Ten years later Henry Norris Russell will make the same observation and give it currency. *See also* 1913 AST.

Ⓑ Biology

Ernest Starling coins the term *hormone* in his paper "On the Chemical Correlation of the Functions of the Body." *See also* 1902 BIO.

International Rules of Zoological Nomenclature is the first worldwide attempt at bringing order in zoological classification.

Arthur Harden discovers that intermediate compounds often form in metabolism, compounds required for a reaction to take place but involved neither as original compounds nor as final ones. *See also* 1904 BIO; 1929 CHEM.

Nettie Maria Stevens [b. Cavendish, Vermont, July 7, 1861, d. Baltimore, Maryland, May 4, 1912] and Edmund Beecher Wilson [b. Geneva, Illinois, October 19, 1856, d. 1939] independently and simultaneously discover the chromosomes for sex determination, both working with various insects. *See also* 1902 BIO.

William Bateson demonstrates that some characteristics are not independently inherited (that is, some characteristics are always inherited together), a finding that will be confirmed and explained by Thomas Hunt Morgan. *See also* 1865 BIO; 1910 BIO.

Ⓓ Chemistry

Adolf von Baeyer of Germany wins the Nobel Prize in chem-

istry for his work on organic dyes. *See also* 1897 CHEM.

⌚ Communication

Guglielmo Marconi invents the directional radio antenna. *See also* 1901 COMM.

㉙ Ecology & the environment

Thomas Crowder Chamberlin writes to Charles Greeley Abbot at the Smithsonian Institution that water vapor and carbon dioxide not only change the temperature of the atmosphere, but also increase and decrease with that temperature, resulting in a complex feedback for the greenhouse effect. *See also* 1859 ECOL.

❖ Materials

Safety glass is patented. It consists of two layers of glass and a layer of celluloid and is widely used for automobile windows. *See also* 1884 MATR; 1920 MATR.

Percy Williams Bridgman [b. Cambridge, Massachusetts, April 21, 1882, d. Randolph, New Hampshire, August 20, 1961] develops the first devices to produce pressures higher than 100 atmospheres, which facilitates the production of artificial diamonds 50 years later. *See also* 1946 PHY.

In St. Petersburg, Russian inventor Alexander Laurent develops a new agent for use in fire extinguishers. The mixture of sodium bicarbonate and aluminum sulfate produces a foam that smothers the fire. *See also* 1866 ENER.

Σ Mathematics

Emanuel Lasker [b. Berlinchen, Germany, December 24, 1868, d. New York City, January 11,

1941], better known as a chess champion than as a mathematician, establishes that every polynomial ideal is a finite intersection of primary ideals (ideals are algebraic structures that are more complex than groups but less than fields). In 1921 Emmy Amalie Noether [b. Erlangen, Germany, March 23, 1882, d. Bryn Mawr, Pennsylvania, April 14, 1935] will generalize this result as part of the foundation of abstract algebra. *See also* 1927 MATH.

♥ Medicine & health

Alexis Carrel [b. Lyon, France, June 28, 1873, d. Paris, November 5, 1944], working at the Rockefeller Institute in New York City, develops techniques for rejoining severed blood vessels, paving the way for organ transplantation. *See also* 1856 MED; 1912 MED.

John B. Murphy [b. Appleton, Wisconsin, December 21, 1857, d. 1916] develops the first artificial joints for use in the hip of an arthritic patient. *See also* 1938 MED.

George Washington Crile [b. Chile, Ohio, November 11, 1864, d. January 7, 1943] performs the first direct blood transfusion in modern times.

Alfred Binet [b. Nice, France, July 8, 1857, d. Paris, October 18, 1911], Victor Henri, and Theodore Simon [b. 1873, d. 1961] develop the first intelligence test. With modifications at Stanford University beginning in 1916, it becomes the widely used Stanford-Binet test. *See also* 1926 MED.

German chemist Alfred Einhorn [b. 1856, d. 1917] synthesizes procaine, also known as Novocain, a local anesthetic that is the first usable substi-

tute for cocaine in medicine. *See also* 1890 MED; 1906 MED.

Fritz Richard Schaudinn, German zoologist [b. Röseningken, Germany, September 19, 1871, d. Hamburg, Germany, June 22, 1906], and Eric Hoffmann discover *Spirocheta pallida*, the cause of syphilis.

Robert Koch of Germany wins the Nobel Prize for physiology or medicine for his tuberculosis research. *See also* 1882 MED.

❖ Physics

Albert Einstein calculates how the movement of molecules in a liquid can cause the “Brownian motion” of small particles suspended in the liquid. This calculation is viewed by many as the first proof that atoms actually exist. *See also* 1827 PHY.

Einstein postulates the light-quantum in his March 17 paper to explain the photoemissive photoelectric effect. His theory explains why the photoelectric effect (release of electrons as a result of electromagnetic radiation striking a metal, varies with the frequency of the light instead of with the intensity), invoking for the first time the idea that entities can be waves and particles at the same time. Later the light particle will come to be

known as the photon. *See also* 1900 PHY; 1921 PHY.

Einstein submits his first paper on the special theory of relativity, “On the Electrodynamics of Moving Bodies,” to the *Annalen der Physik* on June 30. The theory calls the speed of light constant for all conditions and states that time passes at different rates for objects in constant relative motion. A second paper on special relativity, submitted on September 27, “Does the Inertia of a Body Depend on Its Energy Content?” states the famous relationship between mass and energy: $E = mc^2$.

Philipp von Lenard of Germany wins the Nobel Prize in physics for his work on cathode rays. *See also* 1892 PHY.

❖ Transportation

Gabriel Voisin [b. Belleville, France, February 5, 1880, d. December 25, 1973], Ernest Archdeacon [b. Paris, 1863, d. Versailles, France, 1950], and Louis Blériot [b. Cambrai, France, July 1, 1872, d. Paris, August 2, 1936] start the first airplane factory, in Billancourt, near Paris.

The first German U-boat submarine is launched. *See also* 1798 TRAN.

1906

★ Astronomy

Karl Schwarzschild [b. Frankfurt, Germany, October 9, 1873, d. Potsdam, Germany, May 11, 1916] develops the theory that transmission of heat in stellar atmospheres occurs principally by radiation rather than convection or conduction.

Forest Ray Moulton, American astronomer [b. Le Roy, Michigan April 29, 1872, d. December 7, 1952], and Thomas Chamberlin espouse an early version of the planetesimal formation of the solar system (that the planets arose from collisions of smaller bodies called planetesimals), although Moulton and Chamberlin assume that the planetesimals have arisen from an encounter from a passing star, not from condensation, the generally accepted theory today. *See also* 1796 AST; 1944 AST.

❖ Biology

Frederick Hopkins suggests that food contains ingredients essential to life that are not nutrients, such as proteins or carbohydrates. As such substances are found in succeeding years they come to be

called vitamins. *See also* 1897 MED; 1912 BIO.

Clarence Cook Little [b. Brookline, Massachusetts, October 6, 1888, d. December 22, 1971], while a graduate student at Harvard University, starts the first strain of inbred laboratory mice, breeding for coat color. Inbred strains have reduced variation in genes, making them more useful in studies of heredity. *See also* 1929 BIO.

Camillo Golgi of Italy and Santiago Ramón y Cajal of Spain win the Nobel Prize for physiology or medicine for their study of the structure of the nervous system and of nerve tissue. *See also* 1883 BIO; 1893 BIO.

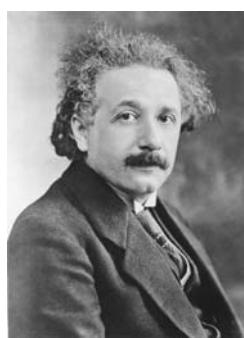
❖ Chemistry

Michael Semenovich Tsvett [b. Asti, Italy, May 14, 1872, d. Voronezh, Russia, June 26, 1919] invents chromatography as a means of separating plant pigments. Although little is made of his idea at the time, it will be popularized in the 1920s by German chemist Richard Willstätter [b. Karlsruhe, Germany, August 18, 1872, d. Locarno, Switzerland, August 3, 1942]. The main importance of chromatography will come when the technique is applied to organic molecules starting in the 1940s. *See also* 1938 CHEM.

Henri Moissan of France wins the Nobel Prize in chemistry for the isolation of fluorine. *See also* 1886 CHEM.

❖ Communication

On December 24 Reginald Fessenden uses his high-frequency alternator to transmit music and voice via radio waves to ships at sea that he has equipped with receivers. The



Einstein, Albert

[b. Ulm, Germany, March 14, 1879, d. Princeton, New Jersey, April 18, 1955]

Einstein's contributions to physics began in 1905 with three major results: the explanation of Brownian motion in terms of molecules; the explanation of the photoelectric effect in terms of the quantum; and the special theory of relativity that links time to space and energy to matter. From 1907 to 1915 Einstein developed general relativity, a theory of gravity more accurate than Newton's; it became the basis of theoretical cosmology. In failed efforts in the 1930s to refute the interpretation of quantum theory in terms of probability, Einstein contributed to the theoretical basis for what is sometimes called teleportation of photons (which Einstein called "spooky action at a distance"). His last major effort was an attempt to unify electromagnetism and gravity into a single unified field theory, still an active problem of physics.

Relativity

Until the end of the 19th century, physicists believed that all physical phenomena, ranging from the motion of atoms to that of celestial bodies, were governed by one set of laws: the laws of motion formulated by Newton in the *Principia*. Newton's theory implied that these laws were also valid for systems that move at constant speed relative to each other. That laws stay the same for such systems is known as the principle of relativity. It is impossible to find from within if a system is uniformly moving or not by performing mechanical experiments. A fundamental concept of Newtonian physics is the existence of absolute space. During the 19th century, when Thomas Young showed that light is a wave phenomenon, an invisible substance called *ether*, linked to absolute space, was believed to be the medium that carried these waves.

During the 1880s Albert A. Michelson and Edward Williams Morley attempted to measure the velocity of Earth relative to the ether by measuring the velocity of light. Their experiments showed that the velocity of light is exactly the same in every direction and thus does not depend on the proper motion of Earth. Some physicists argued that this result showed that the principle of relativity does not apply to electromagnetic radiation. Dutch physicist Hendrik Antoon Lorentz and Irish physicist George Fitzgerald tried to explain that the velocity of light is independent from the motion of Earth by assuming that everything contracts in the direction in which one is moving. They argued that the instrument that Michelson and Morley had used contracted imperceptibly in the direction of Earth's motion, thus falsifying the measurement of the velocity of light. Perhaps the most important aspect of their theory is that they held on to the idea of an ether.

In 1905 Einstein published a theory based on the notion that it is impossible to determine the absolute motion of a moving object. Einstein's concern, however, was not the failure of Michelson and Morley to measure the motion of Earth relative to the ether, but the validity of James Clerk Maxwell's electromagnetic theory in systems that move at speeds close to the velocity of light. Einstein's theory did not require the presence of an ether and was based on the following assumptions: (1) absolute speed cannot be measured, only speed relative to some other object; (2) the measured value of the speed of light in a vacuum is always the same no matter how fast the observer or light source is moving; and (3) the maximum velocity that can be attained in the universe is that of light.

Einstein's theory is called the "special" theory of relativity because it applies the principle of relativity only to systems in uniform motion relative to each other. Because of the principle of relativity, passengers who are traveling smoothly in a train

cannot tell whether they are moving or not unless they look out of a window. The situation becomes different if the train is uniformly accelerated. The passengers will feel a slight push in the direction opposite to that in which the train is moving. This is termed acceleration force: Because of this extra force it appears that the laws of physics would be different for bodies accelerated with respect to each other.

In 1916 Einstein published his general theory of relativity, which he based on the assumption that the laws of physics are also the same in systems that are accelerated relative to each other. To formulate this theory, he introduced the principle of equivalence: Acceleration forces and gravitational forces are not distinguishable from each other. Einstein argued that if one were in a closed elevator that is uniformly accelerated upward, one would perceive a force that is indistinguishable from gravitation. The principle of equivalence can also be expressed by saying that the inertia of an object (its reluctance to be set in motion) is proportional to its mass. The principle of equivalence was already known to Galileo, who had deduced it from his experiments with wooden balls rolling down sloping planes. In 1891 Hungarian scientist Roland Eötvös made precise measurements and established that inertial and gravitational mass are equivalent to an extremely high degree. Because acceleration forces and gravitational forces are equivalent, they should not be distinguishable, but viewed as a property of space.

In a formulation of the special theory, mathematician Hermann Minkowski had introduced a four-dimensional space in which the fourth dimension is time. In this space-time continuum as adapted to the general theory, gravitation corresponds to the amount of curvature in a non-Euclidean, four-dimensional space. Near a large mass, space becomes more curved, and objects moving near that mass will follow the curvature of space.

One of the interesting consequences of the equivalence of gravitation and acceleration force is the bending of light rays by the presence of a large mass, such as a star or planet. For example, if light enters through a small hole on one side of a spaceship that is accelerated, the light ray will reach the other side after the spaceship has moved. The same effect would exist if the spaceship were to come close to a massive planet or star. To an observer in the spaceship, the light ray will appear curved in either case. But the observer cannot tell whether the spaceship is being accelerated or is near a planet or star.

In 1919, during a solar eclipse, Arthur Eddington showed that a star whose light passed close to the Sun appeared to be displaced by a minute amount that corresponded to the value calculated by Einstein. This was the first experimental proof of the general theory of relativity. Several other experiments since then have eliminated most doubts about both theories of relativity among physicists.

transmission is early AM radio — the amplitude (or intensity) of the radio waves varies according to an audio signal that is superimposed on it — although Fessenden calls it wireless telephony. Fessenden requests anyone who hears his signal to write to him and gets replies from as far as the West Indies. This program and another the following night are often considered the first radio broadcasts. *See also* 1904 COMM; 1914 COMM.

Robert von Lieben [b. 1878, d. 1913], Max Dieckmann [b.

1882, d. 1960], and Gustav Glage use the cathode-ray tube for representing television pictures. *See also* 1897 COMM; 1907 COMM.

⊕ Earth science

The great San Francisco earthquake on the morning of April 18 kills about 3000 people and destroys buildings as far away as 600 km (400 mi) from the epicenter. The earthquake is estimated to have a strength of about 8.3 on the Richter scale.

Richard Oldham analyzes

earthquake waves to show that Earth has a core. One kind of wave, called a primary wave or P wave, will travel through both liquids and solids; another kind, the secondary or S wave, will not travel through liquids. The lack of S waves in waves that travel through Earth's center indicates that Earth has a liquid core. *See also* 1866 EAR; 1909 EAR.

Geologist Clarence Edward Dutton [b. Wallingford, Connecticut, May 15, 1841, d. January 4, 1912] suggests that pockets of radioactive miner-

als might account for volcanoes, an idea that is wrong but that calls attention to the role of radioactive heating in the processes of Earth.

In France paleomagnetist Bernard Brunhes [b. 1867, d. 1910] discovers that sediments that are baked into rock by lava contain the same residual magnetism from Earth's magnetic field as lava does. This shows that the residual magnetism is not altered by the direction of flow of the lava but is a direct result of Earth's field when the lava cooled. *See also* 1963 EAR.



SAN FRANCISCO CITY HALL AFTER 1906 EARTHQUAKE Although not the largest earthquake in U.S. history, the 1906 quake along the San Andreas Fault was the most destructive. The earthquake was felt strongly from Coos Bay, Oregon, to Los Angeles in southern California. In San Francisco itself much of the damage was caused by four days of fire that followed the earthquake.



BARRINGER METEORITE CRATER Some 1.3 km (4154 ft) in diameter, the Barringer Meteorite Crater (a.k.a. Meteor Crater) is the most obvious impact crater on Earth. The rim rises 45 m (150 ft) above the desert and the crater is 175 m (570 ft) deep. The crater is now believed to have been caused by an iron asteroid, fragments of which litter the desert around the crater.

Mining engineer and geologist Daniel Moreau Barringer [b. Raleigh, North Carolina, May 25, 1860, d. November 30, 1929] proposes that the large crater in Arizona was caused by a meteorite not by a volcano. It is now known as the Barringer Meteorite Crater.

Electronics

U.S. army colonel Henry H. C. Dunwoody discovers that boron can be used to detect faint electric currents caused by radio waves. About the same time electrical engineer Greenleaf Whittier Pickard [b. Portland, Maine, February 14, 1877, d. Newton, Massachusetts, January 8, 1956] discovers that silicon and other substances, such as galena and iron pyrites, can achieve the same thing. These discoveries lead to the birth of the radio crystal set, popular with hobbyists until radio receivers with tubes (valves) come into use. See also 1901 COMM; 1947 ELEC.

Food & agriculture

In Paris Jacques Arsène d'Arsonval [b. 1851, d. 1940] and George Bordas develop freeze-drying. See also 1898 FOOD.

Materials

Leo Baekeland, who has already made a fortune from his invention of the photographic paper Velox, discovers that a reaction between phenol and formaldehyde produces a synthetic resin (the first ever discovered). At first he uses the resin as an artificial varnish, but by 1909 he converts the resin into the important early plastic Bakelite. See also 1909 MATR.

Mathematics

Maurice René Fréchet [b. Maligny, France, September 2, 1878, d. Paris, June 4, 1973] develops the functional calculus, determining such concepts as limit, continuity, and convergence for a space consisting of real functions over a set.

Medicine & health

German bacteriologist August von Wassermann [b. Bamberg, Germany, February 21, 1866, d. Berlin, March 16, 1925] begins to develop the Wassermann test for syphilis after he observes unexpected destruction of red blood cells appear in his work with syphilis bacteria. Initially very sensitive to the skills of the bacteriologist performing the test, it will be gradually refined into a reliable test after several international "Wassermann conferences" arranged by the League of Nations and various improvements by workers in the field. See also 1910 MED.

Jules Bordet discovers *Bacillus pertussis*, the bacterium causing whooping cough.

Procaine is introduced as a local anesthetic in dentistry. See also 1905 MED.

Alexis Carrel transplants a heart into a dog and a kidney into a cat. This year also, the first modern instance of the transplant of an animal organ

into a human takes place, without success. Mathieu Jaboulay transplants a pig's kidney into one woman and a goat's liver into another. See also 1963 MED.

Physics

Walther Nernst demonstrates that the maximum work obtainable from a process can be calculated from the heat evolved at temperatures close to absolute zero, which is sometimes known as the third law of thermodynamics. See also 1920 CHEM.

J.J. Thomson demonstrates that a hydrogen atom has only a single electron; some previous theories had allowed as many as a thousand electrons per hydrogen atom.

J.J. Thomson of England wins the Nobel Prize for physics for his discovery of the electron. See also 1897 PHY.

Tools

The name *air conditioner* was introduced to describe a device that puts a measured amount of steam into the air

at a textile mill to raise humidity on dry days. Willis Carrier patents his different device, which we know today as the air conditioner, in this year. Its original use is for lowering humidity, and Carrier's patent calls it "Apparatus for Treating Air." See also 1902 TOOL.

✈ Transportation

Enrico Forlanini develops the hydrofoil ship, which uses winglike foils to lift the main hull out of the water, reducing drag. It reaches a top speed of 68.4 km (42.5 mi) per hour. See also 1918 TRAN.

1907

﴿ Biology

Thomas Hunt Morgan begins his work with fruit flies that will prove that chromosomes have a definite function in heredity, establish mutation theory, and lead to fundamental understanding of the mechanisms of heredity in considerable detail. See also 1910 BIO.

Ross G. Harrison [b. Germantown, Pennsylvania, January 13, 1870, d. New Haven, Connecticut, September 30, 1959] demonstrates that he can grow a culture of living animal tissue outside the body (*in vitro* growth). See also 1876 MED; 1931 MED.

Biochemist Henry Clapp Sherman [b. Ash Grove, Virginia, October 16, 1875, d. October 7, 1955] establishes that digestive enzymes are proteins.

Biochemist Thomas Burr Osborne [b. New Haven, Connecticut, August 5, 1859, d. New Haven, January 29, 1929] writes *Proteins of the Wheat Kernel*. His work demonstrates that

proteins come in a vast number of varieties, some of which contain amino acids essential for life. See also 1935 BIO.

Charles Laveran of France wins the Nobel Prize in physiology or medicine for his discovery of the role of protozoa in disease generation. See also 1880 MED.

◊ Chemistry

Emil Fischer synthesizes a polypeptide, or small protein, from amino acids. Containing just 18 amino acids, the synthetic peptide is shown to be broken up by digestive juices just as natural proteins are.

Georges Urbain [b. Paris, April 12, 1872, d. Paris, November 5, 1938] discovers the element lutetium (Lu), which he names after the Roman village that preceded Paris.

Eduard Buchner of Germany wins the Nobel Prize in chemistry for the discovery of non-cellular fermentation. See also 1897 BIO.

⌚ Communication

Reginald Fessenden and Ernst Fredrik Werner Alexanderson [b. Uppsala, Sweden, January 25, 1878, d. May 14, 1975] invent a high-frequency electric generator that produces

radio waves with a frequency of 100 kHz. See also 1906 COMM.

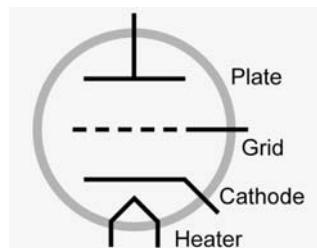
Lee De Forest [b. Council Bluffs, Iowa, August 26, 1873, d. Hollywood, California, June 30, 1961] and R. von Lieben invent the amplifier vacuum tube (triode). It is based on the two-element vacuum tube invented by John Ambrose Fleming but contains a third element, the grid, placed between the cathode and anode that allows the modulation of the current through the valve with very small voltage changes. See also 1904 ELEC; 1912 ELEC.

⊕ Earth science

Bertram Boltwood discovers how to use uranium to find the age of rocks by determining the ratio of uranium to its final decay product, lead. Since the rate of decay of uranium is known and is unaffected by any chemical or mechanical processes, the age can be determined by working in reverse from the ratio. See also 1846 EAR.

◊ Materials

Henri Moissan uses an electric furnace to make tungsten carbide, an ingredient in the pro-



LEE DE FOREST'S TRIODE VACUUM TUBE

The heater supplies enough heat to boil electrons off the cathode, where they are attracted to the plate (the Edison effect). De Forest inserted a grid between the two that is connected to a small electric input — for example, the signal induced by a radio wave — that varies in amount. The negative charge on the grid repels electrons, so they build up before the grid. Fewer or more electrons pass through the grid depending on the strength of the current in the grid. Large changes in current at the plate then reflect the variation of the small charge in the grid.

duction of very hard steel. See also 1893 MATR.

Σ Mathematics

Andrei Andreyevich Markov [b. Ryazan, Russia, June 14, 1856, d. St. Petersburg, Russia, July 20, 1922] develops a theory of linked probabilities in which the probability of one event affects the probability of the following event (Markov chains).



Thomas Hunt Morgan

[b. Lexington, Kentucky, September 25, 1866, d. Pasadena, California, December 4, 1945]

Working mainly with the small fruit fly *Drosophila melanogaster*, Morgan concluded that genes are arranged in a line on chromosomes and that chromosomes are present in the nucleus of every living cell. Morgan also noted occasional recombinations of inherited characteristics and proposed that this results from an exchange of genes between the two chromosomes of a pair, a process he named crossing over.

The age of Earth

Aristotle assumed that Earth always existed, but most peoples throughout history have had different ideas. Eastern philosophy emphasizes cycles of creation and destruction, and the Judeo-Christian belief is that Earth was created once at a specific time. Curious people could use the evidence of the Bible to work out what that time was. The most famous timetable was developed by Archbishop James Ussher in 1650 and further refined by John Lightfoot in 1654. This chronology reported that Earth was created at 9:00 a.m. on October 26, 4004 BCE. The chronology was for the next 200 years or so printed in the margins of the Authorized, or King James, Version of the Bible. Many people in England and other English-speaking countries thought it had always been a part of the Bible. Charles Darwin, for one, was surprised to learn that the Biblical chronology was a recent work of humans.

Mikhail Lomonosov in the 18th century was among the first to see things differently. He thought from geological evidence that Earth must be hundreds of thousands of years old. Perhaps the first attempt to determine the age of Earth on scientific grounds was made by comte de Buffon, who assumed that Earth was originally hot and had slowly cooled. By measuring the rate at which iron balls cool, Buffon decided in 1779 that Earth is about 75,000 years old.

James Hutton in 1785 claimed, as Aristotle indicated, that Earth has "no vestige of a beginning." Hutton's followers, Darwin and Charles Lyell, did not try to determine Earth's beginning, but each made informed guesses as to how long ago certain fossils formed. Darwin dated the end of the Cretaceous period at 300,000,000 years ago (a bit too far back; the currently accepted time is 65,000,000 years ago). Lyell erred on the other

side in 1867, placing the start of the Ordovician period at 240,000,000 years ago; we now think it was about 500,000,000 years ago.

William Thomson (Lord Kelvin) disagreed with both these dates. Using an improved version of Buffon's idea about Earth's cooling, he proposed in 1862 that Earth's crust formed between 20,000,000 and 98,000,000 years ago. He also calculated how long the Sun could have existed, assuming that it got its energy as a result of gravitational contraction. This figure was 100,000,000 years. Geologists did not accept his work, although they had a hard time refuting it.

In 1896, however, radioactivity was discovered. Radioactive elements produce heat, making meaningless Thomson's calculations based on cooling that ignored radioactive heating.

Radioactivity also provided the solution to finding out how old rocks really are. In 1904 Bertram Boltwood and others proved that one element changes into another during radioactive decay. By 1907 Boltwood realized that he could calculate the age of a rock by measuring the ratio of uranium, a fairly common element, to lead, its final decay product. He applied his method to a mineral from Glastonbury, Connecticut, and got an age of 410,000,000 years. (More recent calculations, based on an improved knowledge of isotopes, give the Glastonbury mineral as only 265,000,000 years old.)

Other radioactive elements can be used to date rocks that contain no uranium. Using various adaptations of Boltwood's method, scientists have dated rocks from all periods of Earth's past. Granite from Canada is the oldest known rock, at 3,960,000,000 years old. Zircon crystals, which are especially tough, are the oldest known mineral at about 4,300,000,000 years old. The current best estimate for the age of Earth, based on evidence from meteorites, is 4,600,000,000 years.

Luitzen Egbertus Jan (L.E.J.) Brouwer [b. Overschie, Netherlands, February 27, 1881, d. Blaricum, Netherlands, December 2, 1966] attacks Cantor, Russell, and Hilbert in his doctoral dissertation, "On the Foundations of Mathematics," opposing the formal logic of mathematics and starting his development of the intuitionist school of the foundations of mathematics. *See also* 1908 MATH.

♥ Medicine & health

John Scott Haldane [b. Edinburgh, Scotland, May 3, 1860,

d. Oxford, England, March 14, 1936] develops a method for deep-sea divers to rise to the surface safely — before this, divers often developed the bends (a.k.a. caisson sickness) from nitrogen bubbles forming in the blood. *See also* 1889 MED.

Alois Alzheimer [b. Markbreit, Germany, June 14, 1864, d. December 19, 1915] describes the pathology that in 1910 is given the name Alzheimer's disease.

⌘ Physics

Potassium and rubidium are

found to be slightly radioactive because the normal mix of isotopes for each contains one isotope that is radioactive. Ordinary potassium is not radioactive enough to cause any effects, but rubidium emits enough beta radiation to darken photographic film that has been exposed to it for at least a month.

Pierre-Ernest Weiss [b. Mulhouse, France, March 25, 1865, d. Lyon, France, October 24, 1940] develops the domain theory of ferromagnetism, explaining that iron and other ferromagnetic materials form

small domains of a given polarity. When the poles of the domains are aligned, a strong magnetic force occurs. This explanation is still current. *See also* 1921 PHY.

Albert Michelson of the United States wins the Nobel Prize in physics for his spectroscopic and metrologic study of light. *See also* 1887 PHY.

I Tools

Frederick G. Cottrell [b. Oakland, California, January 10, 1877, d. Berkeley, California, November 16, 1948] patents the electrostatic precipitator,

which removes fly ash, dust, and mist particles from smoke from industrial smokestacks, a process that not only reduces air pollution but also allows some chemicals to be recovered and reused.

→ Transportation

On August 24 (or perhaps September 29) the *Gyroplane*, a helicopter with four propellers built by Louis Charles Bréguet [b. Paris, January 2, 1880, d. Paris, May 4, 1955] and his brother Jacques lifts itself 0.6 m (2 ft) from the ground. It has no pilot, and four men holding it in place with ropes are needed to stabilize it in flight. On November 13 French bicycle dealer Paul Cornu [b. June 15, 1881, d. June 6, 1944] builds the first helicopter that can take off vertically carrying a human. After a 20-second flight at 30 cm (1 ft), however, it breaks up on landing. *See also* 1877 TRAN.

1908

◀ Anthropology

Henri Breuil (a.k.a. Abbe Breuil) [b. Mortain, France, 1877, d. Isle-Adam, France, 1961] discovers a nearly complete Neandertal skeleton, thought by some to have been deliberately buried, in the cave of La Chapelle-aux-Saints, France. It comes to be known as *Le Vieillard* ("the old man"). *See also* 1856 ANTH; 1912 ANTH.

▲ Archaeology

Luigi Pernier discovers a second great palace of the Minoan civilization at Phaistos in southern Crete. In July he uncovers among the ruins a mysterious object now

known as the Phaistos Disk. It is a baked clay disk covered with undeciphered picture writing arranged in a spiral. *See also* 1900 ARCH; 1915 ARCH.

George McJunkin [b. United States, 1851 or 1854, d. 1922] discovers the first known Folsom points, early leaf-shaped stone points from a culture that followed the Clovis culture. The points are associated with fossil bison bones in New Mexico. *See also* 1929 ARCH.

★ Astronomy

George Ellery Hale discovers magnetic fields in sunspots by observing Zeeman splitting of spectral lines. Further work by various scientists eventually shows that sunspots are largely caused by magnetism. *See also* 1904 AST.

Ejnar Hertzsprung proposes identifying the absolute magnitude of stars by considering what the apparent magnitude would be if the stars were at a standard distance of 10 parsecs (32.6 light-years). This idea becomes a standard part of astronomy.

On June 30 a mysterious explosion occurs near Tunguska in Siberia, flattening a huge region and knocking down millions of trees. No meteorite remains are found in the area and the cause is never determined. Later speculation about possible causes ranges from an impact with a comet to an impact with a small black hole, although the most common explanation is a bolide (any sort of space object causing a fireball) that explodes high in the atmosphere.

▴ Biology

Upon a request from Reginald Crundall Punnett [b. Tonbridge,

England, June 20, 1875, d. Bilbrook, England, January 3, 1967], Godfrey Harold Hardy [b. Cranleigh, England, February 7, 1877, d. Cambridge, England, December 1, 1947] works out the mathematical law governing the frequency of a dominant trait in successive generations of a population obeying Mendelian laws of heredity, a problem already solved by German physician Wilhelm Weinberg [b. 1862, d. 1937]. The result is known as the Hardy-Weinberg law — random mating within one generation will produce an approximately stationary genotype distribution with an unchanged gene frequency. *See also* 1909 BIO.

▷ Chemistry

Ernest Rutherford of England wins the Nobel Prize in chemistry for his studies of radioactivity, alpha particles, and the atom. *See also* 1904 PHY.

⌚ Communication

French physicist Gabriel Lippmann wins the Nobel Prize in physics for invention of the first method of color photography. *See also* 1891 COMM.

≡ Electronics

The international ampere is adopted by the International Conference on Electrical Units and Standards. The current balance, based on a design by William Ayrton and J. Viriamu Jones, is used at the National Physical Laboratory in England to measure the absolute ampere; the Weston cell is adopted as the standard voltage source. *See also* 1889 COMM; 1967 COMM.

↗ Energy

Thomas Edison, after eight years of experimentation,

greatly improves his nickel-alkaline battery by adding lithium hydroxide to the electrolyte. Although he does not know exactly why it works, the lithium solves most of the problems with the battery. The Edison Storage Battery Company resumes manufacture, halted in 1910, of batteries, primarily for use in electric-powered vehicles. *See also* 1903 ENER; 1959 ENER.

😦 Food & agriculture

Melitta Bentz [b. Dresden, Germany, January 31, 1873, d. Minden, Germany, June 29, 1950] starts using circles of porous paper to prepare coffee by filtering the coffee through the paper. In 1909 she will exhibits her filter coffee pot at the Leipzig trade fair; by 1912 she will be manufacturing her own line of coffee filters. *See also* 1903 FOOD.

The Holt Company of California develops the first tractor to use moving treads, based on the work of Benjamin Holt. *See also* 1904 TRAN; 1910 FOOD.

◊ Materials

Heike Kamerlingh Onnes succeeds in liquefying helium at a temperature only 4.2°C (7.7°F) above absolute zero. First he cools the helium with liquid hydrogen, which has been available since 1898, and then uses the Joule-Thomson effect to further cool the gas until it liquefies. *See also* 1898 MATR; 1913 PHY.

Fritz Haber [b. Breslau (Wrocław, Poland), December 9, 1868, d. Basel, Switzerland, January 29, 1934] in Germany invents the Haber process for extracting nitrogen from air in the form of ammonia, although his process is not



Heike Kamerlingh Onnes

[b. Groningen, Netherlands, September 21, 1853, d. Leiden, Netherlands, February 21, 1926]

Kamerlingh Onnes continued the work of James Dewar in liquefying gases, achieving liquid helium (the coldest liquid gas) in 1908. Three years later he recognized that certain metals, such as mercury, tin, or lead, when cooled to the temperature of liquid helium — below -268.9°C (-454°F) — conduct electricity with zero resistance, the phenomenon known as superconductivity.

commercially feasible. Cheap ammonia, when manufactured, becomes the main source of nitrate for agriculture, replacing guano. *See also* 1918 CHEM.

Alfred Wilm [b. Niederschelendorf, Germany, June 15, 1869, d. Saalberg, Germany, August 6, 1937] invents duralumin, a strong, lightweight alloy of aluminum containing 3.5 percent copper and 0.5 percent magnesium treated with heat, quick cooling, and aging, which causes the alloy to acquire mechanical strength. Duraluminum becomes useful in airplane construction.

Swiss expatriate Jacques Edwin Brandenburger [b. Zurich, October 19, 1872, d. July 13, 1954] patents cellophane.

Σ Mathematics

L.E.J. Brouwer's *On the Unreliability of Logical Principles* challenges the application of traditional Aristotelian logic to infinite sets. Specifically he rejects the law of the excluded middle (that either a statement or its negation is true) for infinite sets. *See also* 1907 MATH.

Ernst Zermelo gives a set of seven axioms for set theory that, with modifications by Adolf Abraham Halevi Fraenkel [b. Munich, Ger-

many, February 17, 1891, d. Jerusalem, Israel, October 15, 1965], become the standard basis of that subject. Henri Poincaré expresses his famous view of set theory: "Later mathematicians will regard set theory as a disease from which one has recovered." *See also* 1922 MATH.

♥ Medicine & health

The chemical sulfanilamide is discovered, but its bacteria-killing property is not known until after 1936, when it is discovered to be the active part of Prontosil, the first "wonder drug." *See also* 1932 MED.

The tuberculin test, a skin test for tuberculosis based on an immune reaction, is introduced. *See also* 1882 MED.

Paul Ehrlich of Germany and Elie Mechnikov of Russia win the Nobel Prize for physiology or medicine for their pioneering research in the mechanics of immunology. *See also* 1900 MED; 1884 MED.

❀ Physics

Space and Time by Hermann Minkowski [b. Alexotas, Russia, June 22, 1864, d. Göttingen, Germany, January 12, 1909] is an addition to relativity theory. Minkowski shows that relativity theory makes more sense if the universe has four dimensions, with time as

the fourth dimension. *See also* 1905 PHY.

Ernest Rutherford determines that alpha particles are the nuclei of helium atoms. *See also* 1903 PHY.

Jean-Baptiste Perrin shows that Brownian motion is produced by bombardment of neighboring molecules and uses Einstein's formula for Brownian motion to calculate the size of a molecule of water. *See also* 1905 PHY; 1926 PHY.

I Tools

The Hughes Tool Company develops the steel-toothed rock-drilling bit, revolutionizing the oil industry by enabling drilling through hard rock for the first time.

Hans Wilhelm Geiger [b. Neustadt-an-der-Haardt, Germany, September 30, 1882, d. Potsdam (Germany), September 24, 1945] and Ernest Rutherford develop the first form of a radiation detector. It comes to be known as the Geiger counter and detects alpha particles (helium nuclei). *See also* 1928 TOOL.

✈ Transportation

Orville Wright makes the first airplane flight that lasts an hour. *See also* 1905 TRAN; 1909 TRAN.

Elmer Ambrose Sperry [b.

Cortland County, New York, October 21, 1860, d. Brooklyn, New York, June 16, 1930] patents gyrostabilization, a method for reducing roll in ships by tilting forward or backward the vertical axis of spinning gyroscopes; the resulting gyroscopic forces acting to one or the other side of the ship tend to counteract the roll. *See also* 1912 TRAN.

German engineer Hermann Anschütz-Kaempfe [b. 1872, d. 1931] and Max Shuler invent a gyroscopic compass that indicates north and that can be used on iron ships, where a magnetic compass cannot work. *See also* 1852 TRAN; 1911 TRAN.

Henry Ford starts building his Model T, powered by a four-cylinder, 20 hp engine. Over the next 19 years some 15,000,000 Model T's are built.

1909

★ Astronomy

Swedish astronomer Karl Petrus Bohlin [b. 1860, d. 1939] suggests (correctly) that the Sun is at an off-center position in the Milky Way Galaxy. *See also* 1785 AST; 1918 AST.

☒ Biology

Wilhelm Ludwig Johannsen [b. Copenhagen, Denmark, February 3, 1857, d. Copenhagen, November 11, 1927] coins the terms *gene* to describe the carrier of heredity, *genotype* to describe the genetic constitution of an organism, and *phenotype* to describe the actual organism that results from a combination of the genotype and various environmental factors. *See also* 1908 BIO.

British physician Archibald Edward Garrod [b. London, 1857, d. 1939] discovers that some genes function by blocking steps in life processes that would otherwise take place.

Chemistry

Soren Peter Lauritz Sorensen [b. Javrebjerg, Denmark, January 9, 1868, d. Copenhagen, February 12, 1939] introduces pH as a measure of acidity and alkalinity. *See also* 1934 CHEM.

Russian-American chemist Phoebus Aaron Theodor Levene [b. Sager, Russia, February 25, 1869, d. New York, New York, September 6, 1940] discovers that the sugar ribose is found in some nucleic acids, those that we now call ribonucleic acids (RNA). *See also* 1929 CHEM.

Austrian chemist Fritz Pregl [b. Laibach (Yugoslavia), September 3, 1869, d. Graz, Austria, December 13, 1930] develops the first techniques for analyzing tiny amounts of organic chemicals. *See also* 1923 CHEM.

Friedrich Ostwald of Germany wins the Nobel Prize in chemistry for his work on catalysis. *See also* 1888 CHEM.

Communication

Guglielmo Marconi of Italy and Karl Braun of Germany win the Nobel Prize for physics for wireless telegraphy. *See also* 1901 COMM.

Construction

Architect Peter Behrens [b. Hamburg, Germany, April 14, 1868, d. Berlin, February 27, 1940] designs the AEG Turbine Factory in Berlin, Germany, the first factory to use modern curtain-wall techniques based on glass walls

supported by a steel-and-concrete frame. *See also* 1851 CONS; 1918 CONS.

Earth science

Croatian geologist Andrija Mohorovičić [b. Volosko (Yugoslavia), January 23, 1857, d. Zagreb (Yugoslavia), December 18, 1936] discovers the change in earthquake waves that occurs about 30 km (20 mi) below Earth's surface that indicates the Mohorovičić discontinuity, or "Moho" for short. It will be recognized as the boundary between Earth's crust and mantle. *See also* 1906 EAR; 1935 EAR.

John Fillmore Hayford, American engineer [b. Rouses Point, New York, May 19, 1868, d. Evanston, Illinois, March 10, 1925], develops modern methods to determine the shape of Earth, called geodesy. His values, which will be adopted in 1924 by the International Union of Geodesy and Geophysics, show an equatorial radius of 6378.388 km (3693.339 mi). Hayford concludes that the ellipticity of Earth through the poles is 1/297.

On April 6 Robert Peary and African-American explorer Matthew Henson [b. Charles County, Maryland, August 8, 1866, d. 1955] become the first people to reach the North Pole. *See also* 1831 EAR; 1911 EAR.

Materials

Leo Baekeland patents Bakelite, the first plastic that solidifies on heating and the first to be widely used to replace more traditional materials such as wood, ivory, and hard rubber. One day later British scientist James Swinburne files for a patent on the same sub-

stance. *See also* 1906 MATR; 1917 MATR.

Karl Bosch [b. Cologne, Germany, August 27, 1874, d. Heidelberg, Germany, April 26, 1940] improves the process invented by Fritz Haber for obtaining nitrogen compounds from air, making it into a method that can be used in industrial operations. *See also* 1908 MATR; 1931 MATR.

Mathematics

Maurice Fréchet introduces the concept of "abstract space." In mathematics, a space can be any set of elements with some method that relates one element to the others (similar to distance in physical space). In an abstract space, the elements need not be points or even numbers.

In the third edition of *Cours d'analyse de l'École Polytechnique* ("analysis course for l'Ecole Polytechnique"), published between this year and 1915, Camille Jordan introduces the Jordan curve theorem: Every simple closed curve separates a plane into three regions — the curve, its inside, and its outside. Although this result seems obvious, especially since all simple closed curves can be smoothly deformed into a circle, its proof and applications in topology are very deep.

Medicine & health

Charles-Jules-Henri Nicolle [b. Rouen, France, September 21, 1884, d. Tunis, Tunisia, February 28, 1936] discovers that typhus fever is transmitted by the body louse. *See also* 1928 MED.

Emil Theodor Kocher [b. Bern, Switzerland, August 25, 1841, d. Bern, July 27, 1917] of Switzerland wins the Nobel

Prize for physiology or medicine for his work on the thyroid gland. *See also* 1885 MED.

Physics

Ernest Marsden [b. Lancashire, England, February 19, 1889, d. December 15, 1970], under the direction of Hans Geiger and Ernest Rutherford, determines that some alpha particles bounce back from a thin gold foil, an experiment that leads to Rutherford's correct view of the atom as a nucleus surrounded by electrons. *See also* 1904 PHY; 1913 PHY.

Transportation

Ole Evinrude [b. Norway, April 19, 1877, d. Milwaukee, Wisconsin, July 12, 1934] invents the outboard motor for boats. *See also* 1883 TRAN.

On July 25 Louis Blériot becomes the first human to fly across the English Channel in an airplane, the *Blériot XI*; the trip from Calais to Dover takes 37 minutes. *See also* 1905 TRAN; 1927 TRAN.

1910

Astronomy

In Göttingen, on the suggestion of Ejnar Hertzsprung, Hans Rosenberg [b. 1879, d. 1940] constructs a color-magnitude diagram of the stars in the Pleiades. *See also* 1905 AST.

Biology

Thomas Hunt Morgan discovers that certain inherited characteristics are sex linked as a part of his investigation of the mutation of a fruit fly. A male fly with white eyes appears in a jar of red-eyed flies; in the second generation the white-eyed trait reappears among the male flies. *See also* 1907 BIO; 1926 BIO.

Karl von Frisch, Austrian-German zoologist [b. Vienna, November 20, 1886, d. Munich, Germany, June 12, 1982], shows that fish can see different colors.

Jean Eugène Bataillon produces parthenogenesis (reproduction without sexual union) experimentally in a vertebrate — a frog — by pricking a virgin egg. *See also* 1899 BIO.

Albrecht Kossel of Germany wins the Nobel Prize for physiology or medicine for his study of nucleic acids. *See also* 1879 BIO.

Chemistry

Otto Wallach of Germany wins the Nobel Prize in chemistry for his work with terpenes. *See also* 1884 MATR.

Communication

Radio communications gain much publicity when the captain of the *Montrose* alerts Scotland Yard via radio that the escaping murderer Doctor Albert Crippen is aboard his ship, resulting in Crippen's arrest by detectives from England's Scotland Yard. *See also* 1845 COMM.

Earth science

Geophysicist Harry Fielding Reid [b. Baltimore, Maryland, May 18, 1859, d. Baltimore, June 18, 1944] develops the elastic rebound theory of the cause of earthquakes, in which one fault moving against another causes the quakes. Previous theories assumed that the quakes caused faults rather than the other way around. Reid's work is part of a three-volume report on the great 1906 San Francisco earthquake, issued 1908–10. *See also* 1906 EAR.

Frank Bursley Taylor [b. 1860,

d. 1938] proposes that the continents move from place to place on Earth's surface and that a shallow region in the Atlantic (now recognized as the mid-Atlantic ridge) marks where Africa and South America were once joined. These ideas are essentially the same as those of Alfred Wegener, but Wegener will gather much evidence to support them. *See also* 1850 EAR; 1912 EAR.

Ecology & the environment

Charles Proteus Steinmetz [b. Breslau (Wroclaw, Poland), April 9, 1865, d. Schenectady, New York, October 26, 1923] warns in *Future of Electricity* about air pollution from burning coal and water pollution from uncontrolled sewage disposal into rivers.

Energy

In Paris Georges Claude introduces the neon light.

Food & agriculture

The Holt Company introduces the first gas-propelled combine harvester.

Mathematics

Ernst Steinitz [b. Laurahütte, Germany, June 13, 1871, d. Kiel, Germany, September 29, 1928] writes an early important paper on modern algebra. It is a study of abstract mathematical entities called fields, which are defined by a set of axioms modeled after the rules for rational and real numbers, the most familiar fields. For example, fields have commutative and associative operations of addition and multiplication, 0 and 1 are members, and multiplication is distributive over addition — the product of a sum equals the sum of the products.

Bertrand Russell and English mathematician and philosopher Alfred North Whitehead [b. Ramsgate, England, February 15, 1861, d. Cambridge, Massachusetts, December 30, 1947] start *Principia Mathematica*, a three-volume work that will be completed in 1913. It attempts to derive all of mathematics from pure logic, an attempt that ultimately fails because of paradoxes inherent in axiomatic systems. *See also* 1903 MATH; 1931 MATH.

Medicine & health

Francis Peyton Rous [b. Baltimore, Maryland, October 5, 1879, d. New York, February 16, 1970] discovers that sarcomas in chickens are caused by a virus. *See also* 1892 MED; 1913 MED.

Paul Ehrlich and Sahachiro Hata [b. 1873, d. 1938] introduce salvarsan (arsphenamine), also known as 606, as a "magic bullet," or cure, for syphilis, the beginning of modern chemotherapy. *See also* 1906 MED; 1918 MED.

Major Frank Woodbury of the U.S. Army Medical Corps introduces the use of tincture of iodine as a disinfectant for wounds.

Pathologist Howard Taylor Ricketts [b. Findley, Ohio, February 9, 1871, d. Mexico City, May 3, 1910 (from typhus he catches during research on the transmission of the disease)] demonstrates that Mexican typhus is transmitted by the body louse, as Charles Nicolle had shown for European typhus the year before. *See also* 1909 MED.

Physics

William Henry Bragg [b. Cumberland, England, July 2,

1862, d. London, March 12, 1942] discovers how X rays and gamma rays cause rarified gases to conduct electricity, which occurs because the rays knock electrons out of the gas molecules. He also notes that the waves for X rays and gamma rays behave like particles in this process.

J. J. Thomson uses positive cathode rays to measure atomic masses of several substances and discovers that neon has two isotopes, neon-20 and neon-22, the first confirmation that isotopes, predicted by Frederick Soddy, are possible. *See also* 1919 PHY.

Johannes van der Waals of the Netherlands wins the Nobel Prize for physics for the equation of state for gases. *See also* 1880 PHY.

1911

Anthropology

The first fragments of the "Piltdown man" hoax are discovered in England. *See also* 1912 ANTH.

The Mind of Primitive Man by Franz Boas [b. Minden, Germany, 1858, d. 1942] is published. Boas argues for the equality and equal worth of all societies of human beings and cultures. This is a founding document of cultural anthropology.

Archaeology

Hiram Bingham [b. Honolulu, Hawaii, November 19, 1875, d. 1956] discovers the lost Inca city of Machu Picchu high in the Andes near Cuzco, Peru. At first thought to be a religious community, it will come to be known as a summer retreat for the Inca royal court. Some buildings have astronomical alignments.

Astronomer Andrew Ellicott Douglass [b. Windsor, Vermont, July 5, 1867, d. March 20, 1962], who recognized as early as 1904 that the width of tree rings reflects climate conditions during the tree's annual growth period, collects and matches a number of trees, showing that by matching patterns of rings of similar width, one can determine the specific years in which a tree was growing. *See also* 1929 ARCH.

★ Astronomy

Astronomer Annie Jump Cannon [b. Dover, Delaware, December 11, 1863, d. Cambridge, Massachusetts, April 13, 1941] becomes the curator of the Harvard College Observatory and continues a project started in 1896 of classifying stars by their spectra. She develops the simpler O, B, A, F, G, K, M system of spectral classes (famous for the mnemonic "Oh, be a fine girl — kiss me"), which arranges star types from hottest to coolest. Her work will form the basis of the *Henry Draper Catalogue* of 225,300 stars, published between 1918 and 1924. *See also* 1913 AST.

A meteorite the size of a basketball kills a dog in Nakhla, Egypt, the only recorded case of a meteorite killing a mammal. Seventy-five years later scientists decide that the meteorite originated on Mars.

Ejnar Hertzsprung discovers that the main star forming Polaris, known as alpha Ursae Minoris, is a Cepheid variable. The Cepheid variables are bright stars that vary in brilliance periodically with periods between 1 and 70 days, similar to the prototype of this kind of variable star, delta Cephei. *See also* 1912 AST.

Ⓑ Biology

Thomas Hunt Morgan begins to map the positions of genes on chromosomes of the fruit fly. Morgan explains the separation of certain inherited characteristics that are usually linked as caused by the breaking of chromosomes during the process of cell division. Alfred Henry Sturtevant [b. Jacksonville, Illinois, November 21, 1891, d. Pasadena, California, April 5, 1970], working with Morgan, produces the first chromosome map, showing five sex-linked genes.

Ⓓ Chemistry

Russian-British-Israeli chemist Chaim Weizmann [b. Motol', Russia, November 27, 1874, d. Rehovoth, Israel, November 9, 1952] discovers how to obtain acetone from bacteria involved in fermenting grain, providing an essential ingredient to Britain for cordite during World War I. *See also* 1884 MATR.

Marie Curie of France wins the Nobel Prize in chemistry for her discovery of radium and polonium. *See also* 1898 CHEM.

Ⓛ Communication

Alan Archibald Campbell Swinton [b. Edinburgh, Scotland, 1863, d. 1930] gives the first description of a modern television system with an all-electronic scanning system using cathode-ray tubes in both the transmitter and the receiver. *See also* 1907 COMM; 1919 COMM.

American Bell and Western Electric combine their engineering departments into a single organization, which in 1925 becomes Bell Telephone Laboratories. *See also* 1902 COMM; 1925 COMM.

▀ Computers

Herman Hollerith merges his Tabulating Machine Company with two others to form the Computing Tabulating Recording Company, which will become International Business Machines (IBM) in 1924. His tabulating machines, developed for the U.S. Census, are used in the United Kingdom for the first time for the British Census. *See also* 1896 COMP; 1924 COMP.

Ⓔ Earth science

Geophysicist Augustus Edward Hough Love [b. Weston-super-Mare, England, April 17, 1863, d. Oxford, England, June 5, 1940] discovers the type of earthquake wave now called a Love wave, a surface wave that travels through the crust horizontally (like a sound wave) instead of up and down. The study of Love waves enables scientists to measure the thickness of Earth's crust. *See also* 1906 EAR.

Explorer Roald Amundsen [b. Borge, Norway, July 16, 1872, d. Bering Sea, June 16, 1928] reaches the South Pole. *See also* 1909 EAR.

◊ Materials

German scientist P. Monnartz becomes the first to realize that stainless steels resist corrosion. *See also* 1904 MATR.

William Merriam Burton [b. Cleveland, Ohio, November 25, 1865, d. Miami, Florida, December 29, 1954] introduces thermal cracking for refining petroleum. *See also* 1855 MATR; 1936 MATR.

Otto Diels [b. Hamburg, Germany, January 23, 1876, d. Kiel, Germany, March 7, 1954] begins work on what will become a generally applicable

method for reducing complex organic compounds by heating them with selenium. *See also* 1928 CHEM.

Σ Mathematics

L.E.J. Brouwer establishes that a mapping from one dimension to another cannot occur if the mapping is both one-to-one and continuous. In a continuous mapping, points that are adjacent on the first figure are also adjacent on the map. Georg Cantor's famous one-to-one mapping of the points in a line to the points in a square (showing that both figures have the same number of points) is not continuous, for example. *See also* 1892 MATH; 1912 MATH.

♥ Medicine & health

London physician William Hill develops the first gastroscope, a tube that can be swallowed by a patient so that the doctor may look at the inside of the patient's stomach through the tube. *See also* 1822 MED.

Robert Bárány [b. Vienna, Austria, April 22, 1876, d. Uppsala, Sweden, April 8, 1936] investigates the workings of the labyrinth in the inner ear, including developing clinical means of diagnosing causes of dizziness and theoretical explanations for equilibrium problems. *See also* 1914 MED.

Allvar Gullstrand invents the slit lamp for use in ophthalmology. *See also* 1851 MED.

Allvar Gullstrand of Sweden wins the Nobel Prize for physiology or medicine for his work on refraction of light in the eye. *See also* 1899 MED.

❀ Physics

Heike Kamerlingh Onnes discovers superconductivity, the ability of a substance to conduct

electricity with no resistance. He finds the phenomenon in mercury that has been cooled to a temperature close to absolute zero. *See also* 1908 MATR.

Frederick Soddy observes that whenever an atom emits an alpha particle, it changes to an element that is two places down in the list of atomic masses (an important precursor of the concept of atomic number). *See also* 1913 PHY.

Owen Richardson develops the theory behind the Edison effect, which is that heated metals emit electrons. This effect is the basis of the vacuum tubes (a.k.a. valves) used in electric devices such as radios and early computers. *See also* 1883 PHY; 1928 PHY.

On May 7 Ernest Rutherford presents his theory of the atom to the Manchester Literary and Philosophical Society. He (correctly) envisions the atom as consisting of a positively charged nucleus surrounded by negative electrons. *See also* 1909 PHY; 1913 PHY.

→ Transportation

U.S. inventor Charles Franklin Kettering [b. Loudonville, Ohio, August 29, 1876, d. Loudonville, November 25, 1958] develops the first practical self-starter for automobiles.

On July 4 a Valkyrie B canard (pusher) airplane designed by Horatio Barber [b. 1875, d. 1964] delivers in Great Britain the first known air cargo, a carton of Osram lamps. *See also* 1914 TRAN.

The first escalators are introduced at the Earl's Court underground station in London. A man with a wooden leg is hired to ride up and down

regularly to demonstrate their safety. *See also* 1887 TRAN.

About this time the Forbes ship's log is invented, a device for measuring a ship's speed that protrudes from the bottom of the ship instead of being dragged. *See also* 1861 TRAN.

Elmer Sperry invents his version of the gyrocompass. *See also* 1908 TRAN; 1912 TRAN.

The white line marking the center of a highway is first used in the United States in Indio, California. It is suggested by resident Dr. June MacCarroll after a near accident with an oncoming truck. The idea will be adopted by the California Highway Commission in 1928 and from there will spread across the United States.

1912

◀ Anthropology

French paleontologist (Pierre) Marcellin Boule [b. January 1, 1861, d. July 4, 1942] completes his reconstruction of the skeleton of a Neandertal man, known as the old man of La Chapelle-aux-Saints. Boule's misinterpretation of features caused by illness or adaptation to a cold climate results in an image of the Neandertal as a shuffling, stupid brute. A reanalysis of the skeleton in the 1950s reveals Boule's errors. *See also* 1908 ANTH.

British amateur archaeologist Charles Dawson finds "Piltdown man" in Sussex. The skull resembles that of modern man while the lower jaw has characteristics of an ape. Although this combination of characteristics accords with anthropologists' expectations at the time, later discoveries make this combination seem unlikely. In 1953

it will be established that the fossil is a hoax. *See also* 1911 ANTH; 1953 ANTH.

★ Astronomy

Studies of short-period variable stars by Henrietta Swan Leavitt [b. Lancaster, Massachusetts, July 4, 1868, d. Cambridge, Massachusetts, December 12, 1921] in the Small Magellanic Cloud lead to the period-luminosity law of Cepheid variables; that is, the luminosity of a Cepheid variable star can be determined from its period. This turns out to be the key to unlocking the distances to galaxies. *See also* 1911 AST; 1929 AST.

Austrian-American Victor Franz (Francis) Hess [b. Schloss Waldstein, Austria, June 24, 1883, d. Mt. Vernon, New York, December 17, 1964] discovers that ionization of air increases with height during a balloon ascent. This indicates the existence of what we now call cosmic rays. *See also* 1900 PHY.

Vesto Melvin Slipher [b. Mulberry, Indiana, November 11, 1875, d. Flagstaff, Arizona, November 8, 1969] is the first to obtain the spectrum of a spiral nebula (galaxy), the Andromeda Galaxy. *See also* 1929 AST.

Heber Doust Curtis [b. Muskegon, Michigan, June 27, 1872, d. Ann Arbor, Michigan, January 9, 1942] discovers the first recognized cosmic jet (in the giant elliptical galaxy M87).

❖ Biology

Polish-American biochemist Casimir Funk [b. Warsaw, February 23, 1884, d. New York, New York, November 20, 1967] coins the term *vitamin* for a class of substances

that Frederick Hopkins had found to be important to health and that had previously been called accessory food factors. *See also* 1906 BIO.

▷ Chemistry

Victor Grignard and Paul Sabatier of France win the Nobel Prize in chemistry, Grignard for his discovery of Grignard reagents and Sabatier for his catalytic hydrogenations compounds. *See also* 1899 CHEM; 1897 CHEM.

↳ Communication

German chemists Siegrist and Fisher develop a subtractive form of color photography with color formers embedded in three layers of emulsion, a predecessor of the commercial color photography systems called the Agfacolor and Kodachrome processes. *See also* 1908 COMM; 1935 COMM.

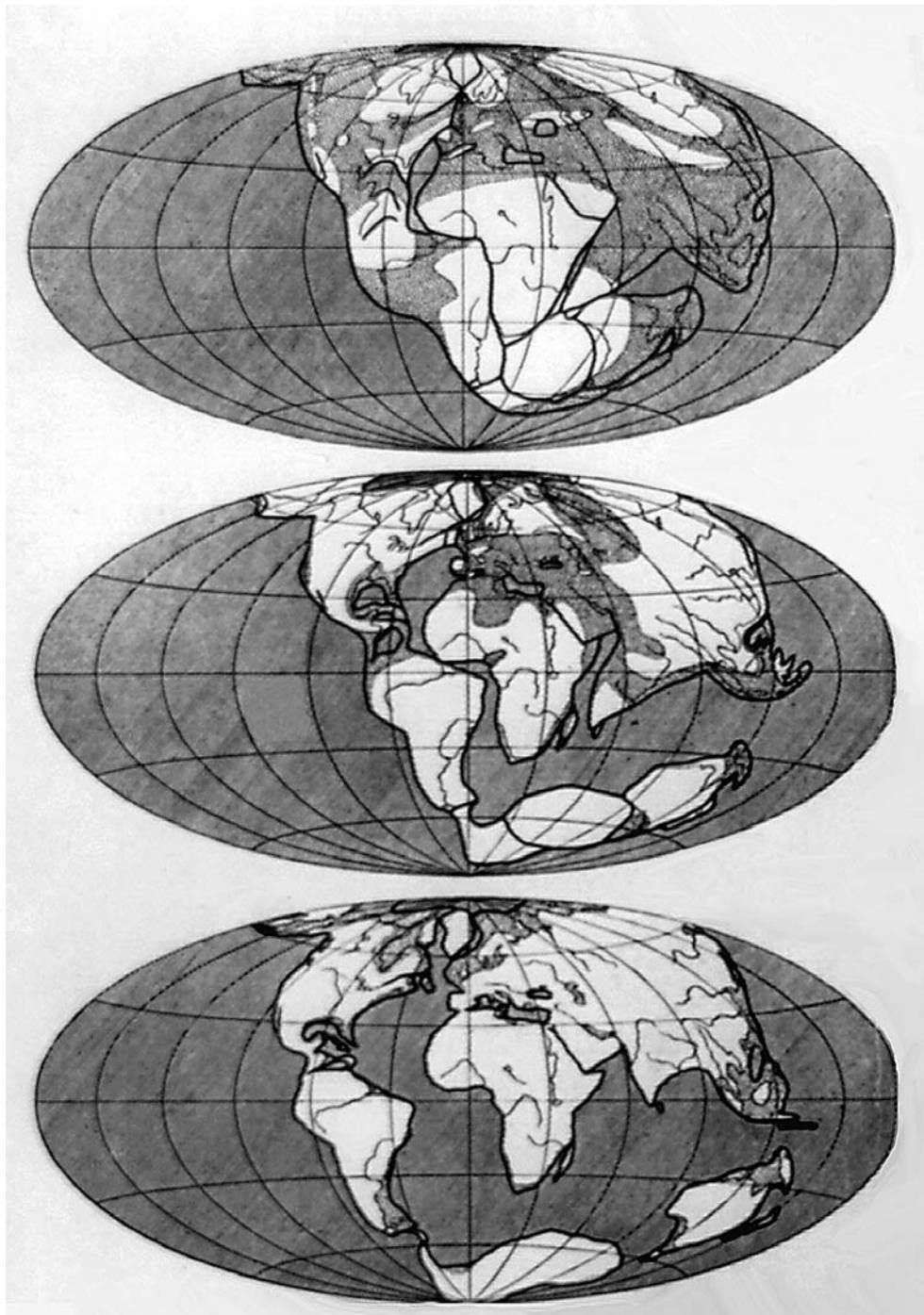
⊕ Earth science

German geologist and meteorologist Alfred Wegener first proposes his theory of continental drift and the supercontinent of Pangaea. *See also* 1910 EAR; 1915 EAR.

Alfred Lothar Wegener

[b. Berlin, Germany, November 1, 1880, d. Greenland, November 1930]

Trained as an astronomer, but working mostly as a meteorologist, Wegener is primarily remembered for his contribution to geology, the theory of continental drift. He named and described Pangaea and provided cogent arguments as to how this supercontinent broke into today's separate continents about 200,000,000 years ago. Although Wegener was not the first to recognize the breakup and separation of continents, he was the most effective advocate for the idea.



WEGENER'S THEORY OF CONTINENTAL DRIFT Wegener proposed that in the Upper Carboniferous period — roughly 300,000,000 years ago — all the continents were merged into a single land mass, which he called Pangaea ("all Earth"), but by the Eocene epoch — about 60,000,000 years ago — they had drifted apart. As they continued to drift, they moved into the positions that we know today. While this theory was flawed in some ways, the general concept of a single Pangaea followed by the movement of continents into the configuration we know today is now considered correct.

Electronics

Lee De Forest develops the audion amplifier, a three-tube amplifier that increases the strength of an audio signal 120 times. Fritz Lowenstein in New York develops the "ion controller" amplifier, which consists of a De Forest audion tube with a negative voltage applied to the grid (negative bias). See also 1907 COMP; 1915 ELEC.

Energy

Austrian Victor Kaplan [b. 1876, d. 1934] patents his first turbine, a propeller turbine mounted on a vertical shaft. The propeller has adjustable blades and guide vanes so that its efficiency remains maximum at different workloads.

Nils Gustaf Dalén wins the Nobel Prize for physics for inventing automatic gas regulators for lighthouses and sea buoys. See also 1901 ENER.

Materials

Friedrich Bergius [b. Goldschmieden, Germany, October 11, 1884, d. Buenos Aires, Argentina, 1949] begins developing a method to use high-pressure hydrogen to saturate coal and petroleum, leading by 1927 to the liquefaction of coal. See also 1931 MATR.

Mathematics

L.E.J. Brouwer's *Intuitionism and Formalism* details the principles of the intuitionist movement in mathematics. Intuitionism is a movement by a relatively small group of mathematicians to base mathematics on the natural numbers, which intuitionists feel are understood intuitively, and to reject mathematical entities that cannot be constructed. See also 1911 MATH.

♥ Medicine & health

James B. Herrick [b. 1861, d. 1954], in "Clinical Features of Sudden Obstruction of the Coronary Arteries," is the first to describe heart disease in terms of damaged arteries and to propose that a heart attack is caused when a blood clot blocks the flow to the heart. *See also* 1925 MED.

Alexis Carrel of France wins the Nobel Prize for physiology or medicine for vascular grafting of blood vessels. *See also* 1905 MED.

* Physics

Max Theodor Felix von Laue, German physicist [b. Pfaffendorf, Prussia, October 9, 1879, d. Berlin, April 23, 1960], demonstrates that X rays are a form of electromagnetic radiation by creating diffraction patterns with crystals. This work also shows that crystals actually do have the periodic structure of molecules that had been predicted. Inspired by the work of von Laue, William Henry Bragg, working with his son William Lawrence [b. Adelaide, Australia, March 31, 1890, d. Ipswich, England, July 1, 1971], measures the wavelength of X rays using the structure of crystals to scatter the X rays. *See also* 1902 PHY; 1914 PHY; 1915 PHY.

Einstein proposes the theory of interactions of electrons and light that will eventually give rise to the laser. *See also* 1905 ENER; 1957 ELEC.

✈ Transportation

On April 15 the supposedly unsinkable *Titanic* sinks on its maiden voyage after striking an iceberg; 1500 people perish. Although it was intended to be kept afloat by watertight

bulkheads, the rip in its side permitted water to flow into enough compartments to sink the ship. *See also* 1986 TRAN.

A prototype gyrostabilization system developed by Elmer Sperry is installed in the 433-ton torpedo-boat destroyer *Worden*. Two gyro wheels weighing 1814 kg (4000 lb) succeed in reducing roll from 30 degrees to about 6 degrees. *See also* 1908 TRAN.

Sulzer, a firm in Switzerland builds the first diesel locomotive. Weighing 85 tons, it develops 1200 hp. *See also* 1930 TRAN.

1913

* Astronomy

Henry Norris Russell [b. Oyster Bay, New York, October 25, 1877, d. Princeton, New Jersey, February 18, 1957] announces his theory of stellar evolution. Independently discovered by Ejnar Hertzsprung in 1905, this concept is pictured in the famous Hertzsprung-Russell diagram and interpreted as showing how stars change with time. *See also* 1905 AST.

Ejnar Hertzsprung becomes the first to use Cepheid variable stars to estimate distances to the stars. *See also* 1912 AST; 1914 AST.

The Harvard spectral classification of stars developed by Annie Jump Cannon is adopted by the International Solar Union. *See also* 1911 AST.

↗ Biology

Elmer Verner McCollum [b. near Fort Scott, Kansas, March 3, 1879, d. Baltimore, Maryland, November 15, 1967] and his assistant Marguerite Davis identify a fat-soluble vitamin

later called vitamin A to distinguish it from the water-soluble vitamin discovered by Christiaan Eijkman termed vitamin B. *See also* 1897 MED.

Alfred Henry Sturtevant reports that double crossing over of genes occurs on chromosomes and that the frequency of this event can be used to determine the order of three genes on a chromosome. *See also* 1911 BIO.

Archibald Vivian Hill [b. Bristol, England, September 26, 1886, d. 1977] discovers that muscle cells respire, or use oxygen, after a contraction is finished, not while the contraction is taking place. *See also* 1922 MED.

Ramón y Cajal develops a stain for distinguishing the fine structure of nervous tissue, and uses it to prove the presence of astrocytes (star-shaped nerve cells) in the brain. *See also* 1906 BIO.

High-school teacher Johann Regan ingeniously uses the newly available telephone to determine if it is true that a male cricket's call is a mating signal to a female cricket. When a male cricket chirps over the telephone, the female immediately heads for the earpiece, confirming the hypothesis.

▷ Chemistry

Kasimir Fajans [b. Warsaw, Poland, May 27, 1887, d. Ann Arbor, Michigan, May 18, 1975] discovers the chemical element protactinium (Pa).

Max Bodenstein, German chemist [b. Magdeburg, Germany, July 15, 1871, d. Berlin, September 3, 1942], develops the concept of a chemical chain reaction, where one

change in a molecule causes the next change and so on.

Theodore William Richards [b. Germantown, Pennsylvania, January 31, 1868, d. Cambridge, Massachusetts, April 2, 1928], who has specialized in determining atomic weights with great accuracy, finds that the element lead from different minerals has a different atomic weight. This result tends to confirm the theory of isotopes announced by Frederick Soddy earlier in the year since it can be explained best if lead is a mixture of isotopes, each with a different atomic mass. *See also* 1910 PHY; 1914 CHEM.

György von Hevesy [b. Budapest, Hungary, August 1, 1885, d. Freiburg-im-Breisgau, Germany, July 5, 1966] and Friedrich Adolf Paneth [b. Vienna, Austria, August 31, 1887, d. Mainz (Germany), September 17, 1958] use radioactive lead to trace the solubility of lead salts, demonstrating that even a small amount of the chemical can be used as a radioactive tracer. *See also* 1935 BIO.

Alfred Werner of Switzerland wins the Nobel Prize in chemistry for his study of the bonding of atoms. *See also* 1891 CHEM.

☛ Communication

The cascade-tuning radio receiver and the heterodyne radio receiver are introduced. *See also* 1901 COMM; 1914 COMM.

Vacuum triodes are used in repeaters in telephone lines for the amplification of weak signals. The first "audion repeaters" are used on the line New York to Baltimore. *See also* 1914 COMM.

Edouard Belin [b. Vesoul, France, March 5, 1876, d. Terriet, Switzerland, March 4, 1963] invents a portable facsimile machine (fax), which he calls the Belinograph but which journalists of the time know as the Belino. Capable of using ordinary telephone lines, the Belino quickly replaces the fax machine of Arthur Korn, which requires its own electric lines. *See also* 1902 COMM; 1914 COMM.

Alexander Meissner [b. Vienna, Austria, September 14, 1883, d. Berlin, January 4, 1958] invents a radio transmitter based on vacuum tubes (valves in British English). *See also* 1907 COMM.

■ Construction

The Woolworth Building is constructed in New York City. At 232 m (791 ft) it is the tallest office building in the world for the next quarter century, although shorter than the Eiffel Tower. *See also* 1903 CONS; 1930 CONS.

■ Earth science

Physicist Charles Fabry [b. Marseille, France, June 11, 1867, d. Paris, December 11, 1945] discovers that there is an ozone layer in the upper atmosphere. *See also* 1840 CHEM; 1974 ECOL.

Arthur Holmes, English geologist [b. Hebburn on Tyne, Durham, England, January 14, 1890, d. London, September 20, 1965], uses radioactivity to date various rock formations, reaching the conclusion that Earth is about 1,600,000,000 years old, three billion years short of the currently accepted age. On the basis of his studies, he proposes the first version of the geological time scale, dating various periods

in Earth's history. *See also* 1907 EAR.

■ Energy

British engineer Harry Ralph Ricardo [b. London, January 26, 1885, d. Graffham, England, May 18, 1974] demonstrates that knock in gasoline engines is caused by the spontaneous detonation of the gas mixture in the cylinder caused by compression. *See also* 1893 ENER; 1921 ENER.

Irving Langmuir [b. Brooklyn, New York, January 31, 1881, d. Falmouth, Massachusetts, August 16, 1957], while working for General Electric, improves the tungsten lamp by filling the bulb with an inert gas so that atoms of tungsten will evaporate more slowly from the filament. He also develops the coiled tungsten filament. *See also* 1910 ENER; 1933 ENER.

■ Food & agriculture

Carl Gustav De Laval perfects a vacuum milking machine. *See also* 1890 FOOD.

The first home refrigerator, the Domlre, goes on sale in Chicago. It is not very successful but soon followed by others in the American market. *See also* 1918 FOOD.

■ Mathematics

Srinivasa Ramanujan [b. Tanjore district, Madras, India, December 22, 1887, d. Kum-

bakonam, India, April 26, 1920] writes on January 16 to English mathematician G.H. Hardy and encloses a number of remarkable results in infinite series that he has developed. Hardy soon invites the self-taught Ramanujan to England, where the young Indian keeps up his flow of new ideas. *See also* 1917 MATH.

■ Medicine & health

Bela Schick [b. Boglar, Hungary, July 16, 1877, d. New York, December 6, 1967] introduces the Schick test for diphtheria. *See also* 1908 MED.

Emil von Behring introduces a toxin-antitoxin mixture for immunizing children against diphtheria. *See also* 1897 MED; 1923 MED.

John Jacob Abel [b. Cleveland, Ohio, May 19, 1857, d. Baltimore, Maryland, May 26, 1938] develops the first artificial kidney. *See also* 1943 MED.

German surgeon Albert Salomon develops mammography for diagnosing breast cancer. *See also* 1911 MED.

Johannes Andreas Grib Fibiger [b. Silkeborg, Denmark, April 23, 1867, d. Copenhagen, January 30, 1928] induces cancerous growths in rats by exposing them to a nematode, then identified by the genus name *Spiroptera*. The resulting can-

cer is dubbed the Spiroptera carcinoma. *See also* 1910 MED; 1926 MED.

John Broadus Watson [b. Greenville, South Carolina, January 9, 1878, d. New York, New York, September 25, 1958] publishes his first paper on behaviorism, which defines psychology as a study of observable behavior.

Charles Robert Richet wins the Nobel Prize for physiology or medicine for his work on anaphylaxis allergy. *See also* 1902 MED.

■ Physics

Frederick Soddy, Kasimir Fajans, and Alexander S. Russell observe that when an atom emits a beta particle, it changes into an atom one place up in a list of atoms by atomic mass, another clue to the concept of atomic number. On February 18 Soddy coins the term *isotope* to describe atoms that are the same element but that have different atomic mass. *See also* 1911 PHY; 1921 CHEM.

Henry Moseley deduces the place of elements in the periodic table from their X-ray spectra and formulates his law of numbers of electrons: An element has the same number of electrons as its atomic number. Antonius Johannes van den Broek notes that atomic mass and the number

Henry Gwyn Jeffreys Moseley

[b. Weymouth, England, November 23, 1887, d. in action at Gallipoli, Turkey, August 10, 1915]

Moseley used X-ray diffraction to show that each element has an atomic number. With this tool he was able to predict elements for the six remaining gaps in the periodic table and to resolve identities of rare earths.



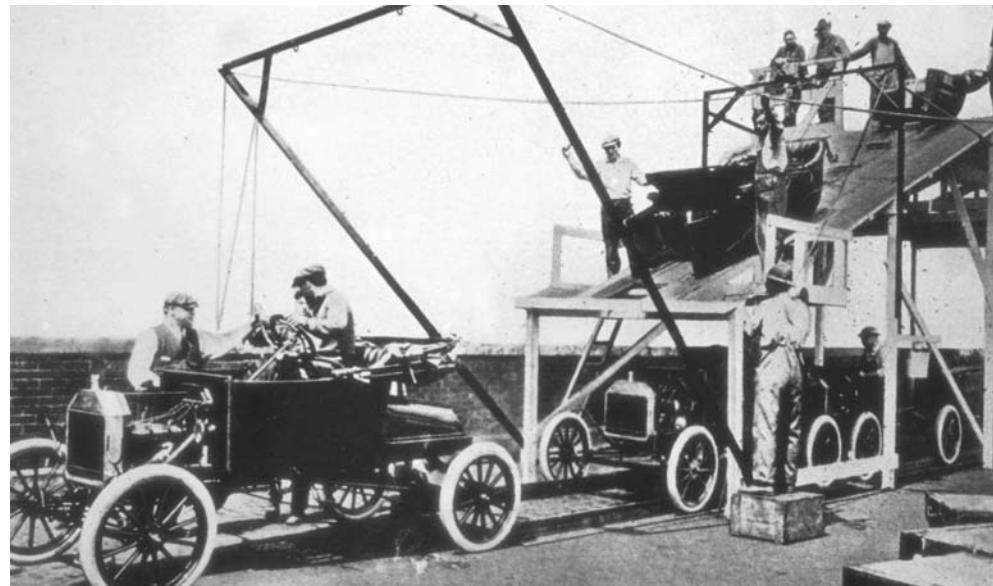
of electrons in an atom are independent, but fails to recognize the concept of atomic number. *See also* 1911 PHY.

A famous trilogy of papers on the constitution of atoms and molecules by Niels Bohr [b. Copenhagen, Denmark, October 7, 1885, d. Copenhagen, November 18, 1962] is written. Bohr assumes that electrons orbit the nucleus in fixed orbits and give off or absorb fixed amounts of energy (quanta) by jumping from one orbit to another. This energy appears as electromagnetic radiation. Bohr also proposes that beta-decay (spontaneous emission of an electron by a heavy atom) is a nuclear process. *See also* 1911 PHY.

Finnish mathematician Karl Fritiof Sundman [b. Helsinki, October 28, 1873, d. 1949] finds a theoretical solution to the three-body problem (determining the exact orbits of three bodies in space as their gravitational forces affect each other), contradicting the generally held belief that such a solution is impossible.

Johannes Stark [b. Schickenhof, Germany, April 15, 1874, d. Traunstein (Germany), June 21, 1957] discovers that spectral lines of a light source split when the light source is placed in an electric field (the Stark effect). *See also* 1919 PHY.

Robert Andrews Millikan [b. Morrison, Illinois, March 22, 1868, d. Pasadena, California, December 19, 1953] completes a seven-year study of the value of the charge of the electron (the famous "oil drop" experiment), which will contribute to his winning the Nobel Prize. *See also* 1923 PHY.



THE FIRST AUTOMOBILE ASSEMBLY LINE Ford Model T's roll off the first assembly line after five years of experimentation in how to build the car more efficiently. To produce the single model, available only in black, each worker was trained to perform one task over and over, and the car moved from one worker to another as it was built. Model T's were produced rapidly and cheaply. The following year Ford assembly-line workers got a big raise to \$5 a day, possible because of increased productivity.

Heike Kamerling Onnes of the Netherlands wins the Nobel Prize for physics for his work in low temperature physics and liquefaction of helium. *See also* 1908 MATR.

Henry Ford introduces the first true assembly line, where cars are carried along a conveyor belt at a speed slow enough for workers to assemble them but fast enough to reduce the assembly time from 12.5 to 1.5 hours.

→ Transportation

American engineer Frederick Kolster [b. Geneva, Switzerland, January 13, 1883, d. 1950] develops a radio-compass system for ships in the North Atlantic. It uses transmitters on the New Jersey coast. *See also* 1906 COMM; 1928 TRAN.

1914

★ Astronomy

Sir Arthur Stanley Eddington [b. Kendal, England, December 28, 1882, d. Cambridge, England, November 22, 1944] suggests in *Stellar Movements and the Structure of the Universe* that spiral nebulae are galaxies similar to the Milky Way. *See also* 1865 AST; 1924 AST.

American astronomer Walter Sidney Adams [b. Kessab, Turkey, December 20, 1876, d. Pasadena, California, May 11, 1956] introduces the mis-named method of spectroscopic parallax. It is a method of deducing a star's real magnitude from its spectrum, which can then be compared with its apparent magnitude

to obtain an approximation of its distance.

An article by Harlow Shapley [b. Nashville, Missouri, November 2, 1885, d. Boulder, Colorado, October 20, 1972], "On the Nature and Cause of Cepheid Variation," in the *Astrophysical Journal*, explains that Cepheid variables vary in brightness because of pulsations in size as gas expands and contracts. Shapley also correlates absolute magnitude with period in Cepheid variables. *See also* 1912 AST; 1918 AST.

Vesto Slipher discovers evidence of interstellar dust clouds by studying the spectrum of the nebula NGC 7023. *See also* 1930 AST.

↗ Biology

Henry Hallett Dale [b. London, June 9, 1875, d. Cam-

bridge, England, July 23, 1968] proposes that acetylcholine is a compound involved in the transmission of nerve impulses (he isolates it in 1929). *See also* 1920 BIO; 1936 BIO.

John Broadus Watson's *Behavior: An Introduction to Comparative Psychology* proposes the use of animal experiments in psychology.

Edward Calvin Kendall [b. South Norwalk, Connecticut, March 8, 1886, d. Princeton, New Jersey, May 4, 1972] identifies thyroxin, a hormone secreted by the thyroid gland. *See also* 1896 BIO; 1926 BIO.

Chemistry

Theodore Richards of the United States wins the Nobel Prize in chemistry for his determination of atomic weights. *See also* 1913 CHEM.

Communication

Edwin Howard Armstrong [b. New York, New York, December 18, 1890, d. New York, New York, February 1, 1954] patents on October 6 a radio receiver circuit with regeneration (positive feedback) that he had developed while a student at Columbia University. Part of the amplified high-frequency signal is fed back to the tuning circuit to enhance selectivity and sensitivity. The regenerative receiver will ultimately be replaced by the superheterodyne receiver that Armstrong develops in 1918. *See also* 1918 COMM.

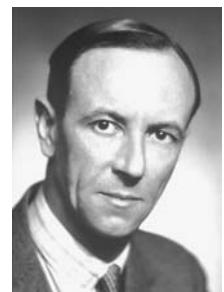
Construction

On November 21 the Yale Bowl opens for the Yale-Harvard football game. With an official seating capacity of 70,869 in a stadium 283 m (930 ft) long and 229 m (750

James Chadwick

[b. Manchester, England, October 20, 1891, d. Cambridge, England, July 24, 1974]

Chadwick's early experiments established that atomic number is determined by the number of protons in an atom (now the definition). In 1932 he discovered the fourth known subatomic particle, the neutron (following the electron, photon, and proton); its existence had been suspected since 1924. Chadwick's later experiments with particle accelerators contributed to the invention of the nuclear fission bomb.



ft) wide, it is the first large football stadium and a model for others. *See also* 70 CE CONS.

Earth science

German-American geologist Beno Gutenberg [b. Darmstadt, Germany, June 4, 1889, d. Los Angeles, California, January 25, 1960] discovers a discontinuity in the behavior of earthquake waves at a depth of about 3000 km (1900 mi); this Gutenberg discontinuity marks the boundary between Earth's mantle and the outer core. *See also* 1909 EAR.

Ecology & the environment

The first modern sewage plant, designed to treat sewage with bacteria, opens in Manchester, England.

Mathematics

Grundzüge der Mengenlehre ("basic features of set theory") by Felix Hausdorff [b. Breslau (Wrocław, Poland), November 8, 1868, d. Bonn, Germany, January 26, 1942] introduces the concept of a topological space, a type of abstract space in which every point has a neighborhood that contains other points. Neighborhoods can be defined in many ways, but for points in a plane the most familiar neighborhood

would be the interior of any circle of nonzero radius surrounding the point. *See also* 1923 MATH.

Medicine & health

Alexis Carrel performs the first successful heart surgery on a dog. *See also* 1893 MED; 1954 MED.

Austrian physician Robert Bárány wins the Nobel Prize for physiology or medicine for his study of inner ear function and pathology. *See also* 1911 MED.

Physics

James Chadwick shows that the electrons produced by radioactivity and observed as beta radiation have a continuous energy spectrum. *See also* 1902 PHY; 1930 PHY.

Ernest Rutherford identifies gamma rays as high-energy electromagnetic radiation, similar to X rays but more powerful. *See also* 1900 PHY.

James Franck [b. Hamburg, Germany, August 26, 1882, d. Göttingen, Germany, May 21, 1964] and Gustav Hertz [b. Hamburg, Germany, July 22, 1887, d. Berlin, October 30, 1975] confirm Niels Bohr's model of the atom by bombarding mercury vapor with electrons and measuring the

frequencies of the emitted radiation, which correspond to the transitions between different energy levels. *See also* 1914 PHY; 1925 PHY.

Max von Laue of Germany wins the Nobel Prize for physics for the crystal diffraction of X-rays. *See also* 1912 PHY.

Tools

The Boston Wire Stitcher Company offers the first desk models of staplers that can be used as modern ones are for joining loose sheets of paper. The staples are either inserted loose or in paper wrappings. This makes them difficult to insert and the machines prone to jamming. *See also* 1923 TOOL.

New York socialite Mary Phelps Jacob designs and patents a brassiere made with elastic. The patent is sold to the Warner Brothers clothing manufacturers. Jacob's design is based on an impromptu version from 1913 whipped up from two handkerchiefs.

Gideon Sundback develops an improved version of a hookless fastener, first sold as Hookless No. 2 on October 28. Essentially, Hookless No. 2 is what we know today as the zipper. *See also* 1923 TOOL.

✈ Transportation

Elmer Sperry invents the autopilot, but it does not go into commercial use until about 20 years later. *See also* 1911 TRAN; 1932 TRAN.

Pilot Tony Jannus [b. Washington, DC, 1889, d. Germany, 1916] runs the St. Petersburg-Tampa Airboat Line for about three months, during that time carrying 1200 passengers across Tampa Bay in a Benoist airboat. This is believed to have been the first passenger airline. The line compiles a 100 percent safety rating before going out of business. *See also* 1911 TRAN.

Red and green traffic lights are introduced for the first time, in Cleveland, Ohio. *See also* 1918 TRAN.

Engineer Robert Hutchings Goddard [b. Worcester, Massachusetts, October 5, 1882, d. Baltimore, Maryland, August 10, 1945] starts developing experimental rockets. *See also* 1903 TRAN; 1919 TRAN.

On August 14 the Panama Canal, constructed largely under the direction of chief engineer George W. Goethals [b. Brooklyn, New York, June 29, 1858, d. New York, January 21, 1928], is officially opened. It is 82.4 km (51.2 mi) long with a minimum depth of 11.8 m (38.8 ft) and a minimum width of 153 m (500 ft). Most of the route is 26.5 m (87 ft) above sea level. *See also* 1904 MED.

1915

▲ Archaeology

Joseph Hatzidakis begins excavation of the Cretan palace at Mallia, the third great palace known from the

Minoan civilization. *See also* 1908 ARCH.

★ Astronomy

Robert Thorburn Ayton Innes [b. Edinburgh, Scotland, November 10, 1861, d. Surbiton, England, March 13, 1933] discovers a faint companion to the double star system Alpha Centauri. The companion is currently the closest known star to Earth except the Sun, and therefore it is often called Proxima (nearest) Centauri.

Walter Sydney Adams measures the temperature of the surface of Sirius B. This invisible (to the naked eye) companion to the bright Sirius A is 2000°C (3600°F) hotter than the Sun. Combined with evidence of its mass, derived from its orbit about Sirius A, this implies that Sirius B is a tiny, extremely dense, hot star — what we now know as a white dwarf. Estonian astronomer Ernst Julius Öpik [b. Port Kunda, Estonia, October 23, 1893, d. Bangor, Northern Ireland, September 10, 1985] works out the first calculations of its density. *See also* 1924 AST.

❖ Biology

On Growth and Form by biologist D'Arcy Thompson [b. 1860, d. 1948] is the first important study of how differential growth rates or different sizes can affect organisms.

R.C. Punnett's *Mimicry in Butterflies* contains the first mathematical analyses of the effects of selection on populations that obey Mendelian laws of heredity. *See also* 1862 BIO.

Frederick William Twort [b. Camberley, England, October

22, 1877, d. Camberley, March 20, 1950] discovers bacteriophages, viruses that prey on bacteria. *See also* 1916 BIO.

● Earth science

Alfred Wegener's *Die Entstehung der Kontinente und Ozeane* ("the origin of continents and oceans") gives several lines of evidence for his 1912 proposal of drifting continents and the supercontinent of Pangaea. *See also* 1912 EAR; 1967 EAR.

■ Electronics

The radio tube oscillator is introduced. *See also* 1913 COMM.

American physicist Manson Benedicks discovers that a germanium crystal can convert a.c. current to d.c., a discovery that will lead to the development of the "chip." *See also* 1906 ELEC; 1947 ELEC.

◊ Materials

The Corning Glass Works develops Pyrex, a heat-resistant glass consisting of 12 percent boron oxide and 80 percent silicon oxide.

♥ Medicine & health

Austrian-American physician Joseph Goldberger [b. Girált, Austro-Hungary (Giraltovce, Slovakia), July 16, 1874, d. Washington, DC, January 17, 1929] establishes that a vitamin deficiency causes pellagra. *See also* 1912 BIO.

✿ Physics

Einstein completes his theory of gravitation, known as the general theory of relativity, on November 25. He has been working on the mathematical problems presented by the theory since 1911. The theory

will be submitted in final form to *Annalen der Physik* on March 20, 1916. *See also* 1861 MATH.

Arnold Johannes Sommerfeld [b. Königsberg (Kalinigrad, Russia), December 5, 1868, d. Munich (Germany), April 26, 1951] introduces the fine structure constant, an important number (almost exactly 1/137) that relates the values of charge, the speed of light, and Planck's constant.

Sir William Henry Bragg and Sir William Lawrence Bragg of England win the Nobel Prize for physics for their study of crystals with X-rays. *See also* 1912 PHY.

I Tools

Physicist Irving Langmuir invents a mercury-vapor condensation pump that creates a nearly perfect vacuum.

✈ Transportation

The British introduce non-rigid airships known as blimps (thought to be named for "type B, limp airship"), which will be used as observation posts during World War I. *See also* 1900 TRAN; 1936 TRAN.

The first all-metal airplane, the Junkers J-1, is built in Germany. It is also the first plane to have cantilever wings that are directly attached to the fuselage instead of being supported by braces and wires. German Fokker aircraft become the first airplanes to be equipped with a machine gun that can fire between the blades of a moving propeller.

The British army develops the tank largely as a way to overcome German barbed wire emplacements. *See also* 1874 FOOD.

French scientist Paul Langevin [b. Paris, January 23, 1872, d. Paris, December 19, 1946] invents sonar, mainly as a method for ships to detect icebergs.

Detroit blacksmith August Fruehauf [b. 1868, d. 1930] invents the tractor trailer, a truck with the cab and engine separate from the main body of the truck.

1916

★ Astronomy

Edward Barnard discovers “a small star with large proper-motion,” meaning that it moves across the sky much faster than normal. Proper motion is the appearance of motion against the background of stars, caused by a combination of actual motion and nearness of the star to Earth. Later astronomers call the small star Barnard’s runaway star, or simply Barnard’s star. The star has the largest proper motion of any star ever found.

Biology

Félix Hubert D’Hérelle [b. Montreal, Canada, April 25, 1873, d. Paris, February 22, 1949] rediscovers the bacteriophages, viruses that prey on bacteria, independently of Frederick Twort’s discovery the previous year. D’Hérelle names them bacteriophages, or “bacteria eaters.” Today they are often called simply phages. See also 1915 BIO; 1942 BIO.

Chemistry

Gilbert Newton Lewis [b. West Newton, Massachusetts, October 25, 1875, d. Berkeley, California, March 23, 1946] explains chemical bonding and valence of chemical elements

by his theory of shared electrons. In his *The Atom and the Molecule* he introduces the even-number rule: The number of electrons in compounds is almost always even. See also 1904 CHEM; 1919 CHEM.

❖ Materials

Artificial detergents are developed in Germany in order to preserve fats for the manufacture of soap (to overcome shortages during World War I).

Kotaro Honda [b. Aichi-ken Prefecture, Japan, February 1870, d. Tokyo, February 12, 1954] discovers that adding cobalt to tungsten steel produces increased magnetic strength, leading to the development of various powerful magnetic alloys that culminate in alnico.

♥ Medicine & health

The natural anticoagulant heparin is discovered in dog livers. See also 1933 MED.

⌘ Physics

Arnold Sommerfeld develops the second quantum number by modifying Niels Bohr’s model of the atom, in which electrons travel in circular orbits, to a model in which the orbits are elliptical. See also 1913 PHY.

Peter Joseph Wilhelm Debye [b. Maastricht, Netherlands, March 24, 1884, d. Ithaca, New York, November 2, 1966] uses powdered crystals to study their structure by observing the X-ray diffraction patterns (powder crystallography). See also 1936 CHEM.

I Tools

American engineer Alva John Fisher develops the first modern electric washing machine.

↗ Transportation

Windshield wipers for automobiles are introduced in the United States.

1917

★ Astronomy

Einstein’s “Cosmological Considerations on the General Theory of Relativity” introduces a model of a static universe and his “cosmological constant” that keeps it static. He later calls the cosmological constant his worst mistake, as various evidence suggests that the universe is expanding. Today the cosmological constant is often equated with the mysterious dark energy that is accelerating expansion of the universe. Willem de Sitter [b. Sneek, Netherlands, May 6, 1872, d. Leiden, Netherlands, November 20, 1934] shows that Einstein’s theory of general relativity proves that the universe must be expanding (provided Einstein’s “correction factor” is left out). Similar calculations will later be undertaken by Alexander Friedmann and Georges Lemaître with similar results. See also 1922 AST.

Karl Schwarzschild develops the equations that predict the existence of black holes from Einstein’s equations for the general theory of relativity. See also 1798 AST; 1939 AST.

George Ellery Hale installs a 2.5-m (100-in.) refracting telescope at Mount Wilson Observatory near Pasadena, California. Known as the Hooker telescope, it will be the world’s largest telescope until 1948, but will be retired from duty in 1987 because of light and air pollution around the observatory and lack of operating funds. A few years

later, retrofitted with adaptive optics, the Hooker returns to service. See also 1934 AST.

❖ Biology

Wolfgang Köhler, Russo-German-American psychologist [b. Revel (Estonia), January 21, 1887, d. Enfield, New Hampshire, June 11, 1967], one of the founders of the Gestalt school of psychology, reports on his experiments with chimpanzees that demonstrate problem-solving ability in *The Mentality of Apes*.

🍴 Food & agriculture

(Clarence) “Bob” Birdseye [b. Brooklyn, New York, December 9, 1886, d. New York, October 7, 1956] begins to develop freezing as a way of preserving foods after experiencing success with naturally frozen foods in Labrador. See also 1906 FOOD.

❖ Materials

The first commercial product made from Bakelite, the first nonflammable plastic, is introduced — the gearshift knob for a Rolls-Royce automobile. See also 1909 MATR.

Σ Mathematics

G.H. Hardy and Srinivasa Ramanujan write on the theory of numbers. Ramanujan had developed several theorems concerning the number of ways that a counting number can be written as the sum of a number of counting numbers. A formula for approximating this number for any counting number is the best known collaborative effort of Hardy and Ramanujan. See also 1913 MATH.

Tullio Levi-Civita [b. Padua, Italy, March 29, 1873, d. Rome, December 29, 1941]

introduces the concept of parallel displacement to the absolute differential calculus, also known as the mathematics of tensors. Tensor analysis is the mathematical basis of Einstein's general theory of relativity. *See also* 1915 PHY.

♥ Medicine & health

Physicians in the United States learn that children develop lead poisoning by eating paint chips that have peeled off of interior walls, especially in poorer neighborhoods (where paint is more likely to be allowed to peel). *See also* 1890 MED; 1955 ECOL.

Julius Wagner von Jauregg [b. Wels, Austria, March 7, 1857, d. Vienna, September 27, 1940] successfully uses malaria to introduce high fevers as a method to treat mental disorders, such as the psychoses caused by syphilis. *See also* 1927 MED.

Mathematician Johann Radon [b. Decin, (Czech Republic), December 16, 1887, d. Vienna, May 25, 1956] develops the mathematics necessary for the invention of the CT scan, showing how to derive three-dimensional data by combining a number of X rays — although the physicist and the engineer who develop the CT scan 40 and 50 years later are unaware of his work. *See also* 1957 MED.

⌘ Physics

Ernest Rutherford discovers that nuclear fission is possible. In the process, Rutherford discovers the proton. *See also* 1911 PHY; 1919 PHY.

Charles Barkla of England wins the Nobel Prize in physics for work on X-ray

scattering by elements. *See also* 1904 PHY.

1918

★ Astronomy

Arthur Stanley Eddington gives a theoretical basis to the pulsation and brightness relationship for Cepheid variables, a concept first described by Henrietta Leavitt in 1912. *See also* 1914 AST.

Harlow Shapley makes the first accurate estimate of the size of the Milky Way Galaxy; his paper "Remarks on the Arrangement of the Sidereal Universe" places the solar system near the outer edge of the galaxy. *See also* 1909 AST.

Kiyotsugu Hirayama [b. 1874, d. 1943] proposes that asteroids are grouped in families. One group of eight families is known today as the Hirayama families (a.k.a. Hirayama/Koronis families).

⌘ Biology

Herbert McLean Evans [b. Modesto, California, September 23, 1882, d. March 7, 1971] finds (incorrectly) that human cells contain 48 chromosomes (later the correct number of 46, in 23 pairs, will be established). *See also* 1954 BIO.

▷ Chemistry

Fritz Haber of Germany wins the Nobel Prize in chemistry for his synthesis of ammonia from atmospheric nitrogen. *See also* 1908 MATR.

⌚ Communication

Edwin Armstrong develops the superheterodyne radio receiver. The incoming signal is mixed with the signal of an internal oscillator that is tuned simultaneously with the receiving cir-

cuit. The signal is transformed to a lower fixed frequency (the intermediate frequency), amplified and demodulated. The superheterodyne principle is the basis for all radio receivers now in use. *See also* 1914 COMM.

■ Construction

Willis Polk [b. Jacksonville, Illinois, 1867, d. San Francisco, 1924] is the first architect to use the curtain-wall construction technique, pioneered by Joseph Paxton around 1850, in a large urban structure, the Hallidie Building in San Francisco. The technique is later made famous by Mies van der Rohe in office buildings in New York City in the 1950s. *See also* 1851 CONS; 1958 CONS.

⊕ Earth science

Jacob Aall Bonnevie Bjerknes, Norwegian-American meteorologist [b. Stockholm, Sweden, November 2, 1897, d. July 7, 1975], writes "On the Structure of Moving Cyclones," which describes how warm and cold air masses move as a front advances and calculates how this produces changes in kinetic energy as a cyclone develops. *See also* 1904 EAR; 1921 EAR.

Vladimir Köppen [b. 1846, d. 1940] develops his climate classification scheme, which remains in use today.

■ Food & agriculture

Kelvinator launches a mechanical refrigerator for home use that is the first successful entry into the field. *See also* 1913 FOOD.

♥ Medicine & health

Schack A.S. Krogh discovers that capillaries in muscles are partially closed when a muscle

is resting and that the capillaries control blood flow in various parts of the body. *See also* 1902 BIO; 1920 BIO.

Walter Abraham Jacobs [b. New York City, December 24, 1883, d. Los Angeles, California, July 12, 1967] and Michel Heidelberger [b. New York City, April 29, 1888, d. New York City, June 25, 1991] create a compound based on Paul Ehrlich's chemical treatment for syphilis. The drug, which becomes known as Tryparsamide, is found to be an effective treatment for one form of African sleeping sickness. *See also* 1910 MED; 1920 MED.

George Hoyt Whipple [b. Ashland, New Hampshire, August 28, 1878, d. Rochester, New York, February 1, 1976] produces the first in a series of papers that describe the effect of diet on the regeneration of blood cells in anemia. *See also* 1925 MED.

Tooth implants, driven directly into a patient's jaw instead of being surgically implanted, are developed. They are not as effective as those of today since they do not bond to the jawbone. *See also* 1889 MED; 1952 MED.

⌘ Physics

Arthur Jeffrey Dempster [b. Toronto, Canada, August 14, 1896, d. Stuart, Florida, March 11, 1950] builds the first mass spectrograph and begins a long career of work with this device that leads to the discovery of, among other things, uranium-235 (in 1935), the essential isotope for fuel in nuclear reactors and the isotope used in the first nuclear bomb. *See also* 1945 TOOL.

Emmy Noether proves that

every symmetry in physics implies a conservation law and vice versa. Eventually this theorem becomes a powerful tool in developing new physical theories. *See also* 1929 PHY.

Max Planck of Germany wins the Nobel Prize for physics for his quantum theory of light. *See also* 1900 PHY.

→ Transportation

Traffic lights incorporating a yellow warning light are introduced in Great Britain. *See also* 1914 TRAN.

Alexander Graham Bell, working with his wife Mabel and engineer F.W. Casey Baldwin, reinvents the high-speed hydrofoil boat. Bell's version attains a top speed of 114 km (70.8 mi) per hour. *See also* 1906 TRAN.

1919

◀ Anthropology

F. Wood Jones argues in "The Origin of Man" that humans diverged from the great apes at a stage similar to that of the modern tarsier. In this view, which is not generally accepted, no common ancestor of humans could be like a monkey or a great ape. *See also* 1860 BIO.

★ Astronomy

Arthur Stanley Eddington and coworkers observe the solar eclipse of May 29 in an effort to determine whether Einstein's general theory of relativity or Newton's theory of gravity predicts best how light from a star will be affected by the gravitational attraction of the Sun; Einstein predicts twice as much bending as

Newton. On November 6, at a joint meeting of the Royal Society and the Royal Astronomical Society in London, the astronomer royal, Sir Frank Watson Dyson [b. January 8, 1868, d. May 25, 1939] announces that the photographs of the eclipse of the Sun taken by the Eddington expedition confirm Einstein's theory of gravitation, not Newton's. *See also* 1915 PHY.

❖ Biology

Karl von Frisch discovers that bees communicate through body movements. *See also* 1958 BIO.

▷ Chemistry

Irving Langmuir develops his theory of covalent bonding of atoms, the chemical binding of two (or more) atoms by the interactions of their outer

electrons. *See also* 1916 CHEM; 1927 CHEM.

⌚ Communication

Shortwave radio is developed.

≡ Electronics

Dutchman Hugo Koch [b. 1870, d. 1928] invents the Enigma, an encoding machine that provides for 22,000,000 combinations, used in World War II by Germany. *See also* 1940 COMP.

William Henry Eccles [b. Ulverston, England, August 23, 1875, d. April 29, 1966] and F.W. Jordan publish a paper on flip-flop circuits. First used in electronic counters, flip-flop circuits become important components in computers some twenty years after this date. *See also* 1937 COMP.

Composites

Traditionally, scientists have classified materials in three classes: metals, plastics, and ceramics. Metals are tough, used mainly for their strength and stiffness; plastics are light and cheap to manufacture; and ceramics are hard, good electrical insulators, and resistant to heat and to corrosion. In recent years, scientists have created materials that do not fit the traditional classifications and that have entirely new properties. High-temperature superconductors are striking examples: They are ceramics that are insulators at room temperature but become superconducting at low temperatures.

Composite materials are combinations of materials from different classes that have properties different from or better than either of their parents. The idea is not new. When the Israelites in Egypt made bricks from clay and straw, the product was a composite.

About 1918 A. A. Griffith discovered that thin glass fibers are very strong but easily broken by any surface damage. Eventually inventors learned to protect the strong fibers with various coatings that enabled them to be treated like other textile fibers. But the real breakthrough came when the fibers became the basis of

a composite. The composite of glass fibers and resin, popular for construction of boats and automobile bodies, is commonly called fiberglass. This material combines the low weight and corrosion resistance of plastic with the tensile strength of glass fibers. Similar composites of carbon fiber and resin have the toughness of steel but are four times lighter; these composites are now widely used in aircraft construction and such specialized applications as fishing rods. This type of carbon fiber used was first created in 1963. By the 1970s "graphite" composites of carbon fiber and epoxy were replacing up to three-quarters of the mass of jet fighter aircraft.

Another fiber with considerable military applications is Kevlar, the tough plastic discovered by Stephanie Kwolek in 1976. It is best known through its application in bulletproof vests, but it also lends its toughness to composite materials similar to fiberglass or graphite-epoxy.

Although not usually thought of as composites, semiconductor devices develop their essential properties as a result of inserting small amounts of one kind of atom into bulk materials of a different atom, a process called doping. The modern electronics industry is based almost entirely on silicon doped with such atoms as arsenic or boron.

❖ Materials

British engineer Alan Arnold (A. A.) Griffith [b. June 13, 1893, d. October 13, 1963] conducts experiments on the fracture of ordinary glass to find the surface tension of a solid. *See also* 1920 MATR.

Frederick Cottrell invents a technique for separating helium from natural gas.

♥ Medicine & health

Jules Bordet of Belgium wins the Nobel Prize for physiology or medicine for his studies in immunology. *See also* 1898 BIO.

✿ Physics

Ernest Rutherford reports on his discovery of two years earlier that some alpha particles striking nitrogen atoms could knock out protons, the first form of artificial atomic fission. The experiment also proves that protons are constituents of the nucleus of the atom.

Heinrich Barkhausen [b. Bremen, Germany, December 2, 1881, d. Dresden, Germany, February 20, 1956] determines why the magnetization of an iron bar proceeds in small jerks accompanied by tiny clicks, now known as the Barkhausen effect. As small magnetic domains become aligned, one at a time, they rub against their neighbors, causing the clicks.

Franz Eugen (Sir Francis) Simon, German-British physicist [b. Berlin, July 2, 1893, d. Oxford, England, October 31, 1956] begins a series of investigations that will continue through 1934 using the paramagnetism of molecules to lower temperatures to very near absolute zero. Paramagnetism is a temporary magnetism induced by a magnetic

field and caused by alignment of the magnetic moments of atoms and molecules. In later experiments Simon also aligns nuclear spins, producing even lower temperatures. *See also* 1933 MATR.

English physicist Francis William Aston [b. Harborne, England, September 1, 1877, d. Cambridge, England, November 20, 1945] builds a mass spectrograph, a device that separates atoms or molecules by mass. He firmly establishes that there are different forms of the same element, which we now call isotopes — the general concept had been known for nearly ten years, however. Different isotopes have the same chemical properties, but the masses of individual atoms are not the same. *See also* 1910 PHY; 1920 PHY.

Johannes Stark of Germany wins the Nobel Prize in physics for his study of the spectral lines in electrical fields. *See also* 1913 PHY.

I Tools

British physicist and engineer Robert Alexander Watson-Watt [b. Brechin, Scotland, April 13, 1892, d. Inverness, Scotland, December 6, 1973] patents his "radiolocator," a system for locating ships or planes by means of radio waves. Because he uses short-wave radio waves instead of microwaves, the precision is low. *See also* 1924 EAR; 1931 TOOL.

➤ Transportation

A Method of Reaching Extreme Altitudes by Robert Goddard suggests sending a small vehicle to the Moon using rockets. Adverse press comments make Goddard disinclined to expose himself to further ridicule. *See also* 1914 TRAN; 1924 TRAN.

Lockheed develops the hydraulic brake system for automobiles. *See also* 1902 TRAN.

1920

★ Astronomy

Albert Michelson measures the diameter of the star Betelgeuse using a stellar interferometer. It is the first measurement of the diameter of any star other than the Sun. *See also* 1996 AST.

Indian astronomer Meghnad Saha [b. Shaoratoli, India, October 6, 1893, d. February 16, 1956] describes ions in the solar chromosphere. He also will show that temperature is as important as elemental composition in determining a star's spectrum.

❖ Biology

German-American biochemist Otto Fritz Meyerhof [b. Hanover, Germany, April 12, 1884, d. Philadelphia, Pennsylvania, October 6, 1951] recognizes that exertion causes glycogen stored in muscles to break down into lactic acid, and that lactic acid combines with oxygen during a muscle's resting phase to restore the glycogen level. *See also* 1918 MED.

Otto Loewi [b. Frankfurt, Germany, June 3, 1873, d. New York, New York, December 25, 1961] proves that acetylcholine is produced at a synapse — the first neurotransmitter to be identified. *See also* 1914 BIO; 1921 BIO.

Henry Clapp Sherman begins his studies of vitamins and minerals. He shows that the ratio of calcium to phosphorus in a diet is as important as the total amount of either mineral, and he investigates the amounts needed for vari-

ous vitamins in the diet of animals. *See also* 1922 BIO.

Schack A.S. Krogh of Denmark wins the Nobel Prize in physiology or medicine for his discovery of the role of capillaries in controlling blood flow. *See also* 1918 MED.

✿ Chemistry

During this decade Irving Langmuir develops the theory of monomolecular films (that is, films just a single molecule thick that form on surfaces) and the absorption of molecules from gases into solids. *See also* 1932 CHEM.

Walther Nernst of Germany wins the Nobel Prize in chemistry for his study of thermodynamics. *See also* 1906 PHY.

☛ Communication

Lee De Forest develops a system to record sound synchronized with pictures on a separate track on photographic film used for cinema, using a photoelectric cell for sound reproduction. This system will be used a few years later in the first talking motion pictures. *See also* 1906 COMM; 1926 COMM.

The first regular licensed radio broadcast, by station KDKA, operated by the Westinghouse Electric and Manufacturing Company in Pittsburgh, takes place. *See also* 1906 COMM; 1923 COMM.

➤ Energy

Several installed Kaplan turbines show damaged blades. Victor Kaplan discovers that the pitting on these blades is caused by cavitation — the formation and collapse of low-pressure bubbles in the liquid. *See also* 1912 ENER.

❖ Materials

The last blast furnace in England still using charcoal to smelt iron, at Backbarrow near Windermere, is modernized to use coke. *See also* 1735 MATR.

A.A. Griffith publishes the basis for a theoretical treatment of the strength of solids and of fracture mechanics. *See also* 1919 MATR.

Charles Guillaume of Switzerland wins the Nobel Prize for physics for his discovery of a special nickel-steel alloy called invar, which resists change in volume with change of temperature, useful in many applications. *See also* 1896 MATR.

♥ Medicine & health

Louise Pearce [b. Winchester, Massachusetts, March 5, 1885, d. August 10, 1959], in field trials in Africa, establishes that Tryparsamide cures one form of African sleeping sickness. *See also* 1918 MED.

Johnson & Johnson introduces the Band-Aid, a sterile-packed individual bandage using tape to hold an absorbent pad in place over a minor cut.

* Physics

William Draper Harkins [b. Titusville, Pennsylvania, December 28, 1873, d. Chicago, Illinois, March 7, 1951] proposes the existence of the neutron, an uncharged particle that will be discovered in 1932 by James Chadwick. *See also* 1932 PHY.

Francis Aston discovers that all atomic masses, when one takes isotopes into account, are very nearly integral multiples of the same number (a number now taken to be 1/12 the mass of carbon-12). *See also* 1886 PHY; 1922 CHEM.

I Tools

Marshal Burns Lloyd [b. St. Paul, Minnesota, March 10, 1858, d. Menominee, Michigan, August 10, 1927] invents a power loom for weaving flat sheets of wicker, the first time that a fiber "fabric" can be created by weaving it apart from a framework. The new form of wicker becomes popular in the United States until replaced about ten years later with furniture based on metal instead of wood and wicker. *See also* 1879 MATR.

Retired U.S. army officer John T. Thompson [b. Newport, Kentucky, December 31, 1860, d. Great Neck, New York, June 21, 1940] patents his submachine gun, later famous as the "tommy gun." *See also* 1884 TOOL.

1921

★ Astronomy

Edward Arthur Milne [b. Hull, Yorkshire, England, February 14, 1896, d. Dublin, Ireland, September 21, 1950] develops an improved mathematical theory of radiation through the solar atmosphere. *See also* 1926 AST.

Alfred Wegener argues convincingly that craters on the Moon are caused by impacts not by volcanic eruptions. *See also* 1873 AST.

❖ Biology

German-American physiologist Otto Loewi establishes that chemicals can stimulate nerves to fire and develops his theory of chemical transmission of nervous impulses. *See also* 1920 BIO; 1936 BIO.

❧ Chemistry

Frederick Soddy of England wins the Nobel Prize in chemistry for his discovery of isotopes of radioactive elements. *See also* 1913 PHY.

⊕ Earth science

Vilhelm Bjerknes's *On the Dynamics of the Circular Vortex with Applications to the Atmosphere and to the Atmospheric Vortex and Wave Motion* shows that the atmosphere is made from sharply differentiated air masses. *See also* 1918 EAR; 1932 EAR.

≡ Electronics

Albert W. Hull [b. Southington, Connecticut, April 19, 1880, d. 1966] invents the first form of magnetron, an electron tube placed in a magnetic field that produces microwaves. At that time normal vacuum tubes could not oscillate at microwave frequencies. *See also* 1932 ELEC.

➤ Energy

Thomas Midgley, Jr. [b. Beaver Falls, Pennsylvania, May 18,

1889, d. Worthington, Ohio, November 2, 1944] discovers that tetraethyl lead prevents knock in gasoline engines, which allows gasoline with the anti-knock additive to be suitable for use in high-compression engines. *See also* 1913 ENER; 1928 MATR.

❖ Materials

Cultured pearls are introduced.

A Boston chemist obtains gelatin from the ears of female pigs, spins it into thread, and uses the thread to weave two purses, one of which is now in the U.S. Smithsonian Institution's National Museum of American History (establishing that if one is clever enough it is possible to make a silk purse from a sow's ear).

♥ Medicine & health

Alexander Fleming discovers the antibacterial substance lysozyme in saliva, mucus, and tears. As with his later discovery of penicillin, a fortuitous accident was involved; he had a cold and some of his mucus dripped onto a culture plate, where it dissolved the bacteria present. *See also* 1928 MED.

Frederick Banting, Charles Best [b. West Pembroke, Maine, February 27, 1899, d. Toronto, Ontario, March 31, 1978], John James Richard Macleod [b. Cluny, Scotland, September 6, 1876, d. March 16, 1935], and

Sir Alexander Fleming

[b. Lochfield, Scotland, August 6, 1881, d. London, March 11, 1955]

In 1921 Fleming discovered an enzyme he called lysozyme. Found in tears, saliva, and other natural substances, lysozyme breaks bonds in the cell walls of bacteria, causing the bacteria to lyse, or break apart. Fleming's most famous discovery came in 1928, when a *Penicillium* mold contaminated a dish in which he was growing the bacterium *Staphylococcus aureus*. Fleming noticed that no *Staphylococcus* grew near the mold, and discovered that the mold produced a powerful antibacterial chemical, which he named penicillin.





Frederick Grant Banting

[b. Alliston, Ontario, Canada, November 14, 1891, d. Musgrave Harbour, Newfoundland, February 21, 1941]

The hormone insulin, which controls blood sugar levels, was first extracted from the pancreas by Banting and Charles H. Best in 1921, using a technique conceived by Banting. In 1922 a 14-year-old boy suffering from type I diabetes mellitus (a disease resulting from insufficient insulin) showed rapid improvement after becoming the first person to be treated with insulin.

James B. Collip [b. Bellville, Ontario, November 20, 1892, d. London, Ontario, June 19, 1965] extract insulin from the human pancreas and start experiments on dogs in an effort to develop a treatment for diabetes. *See also* 1923 MED.

Hermann Rorschach [b. Zurich, Switzerland, November 8, 1884, d. Herisau, Switzerland, April 2, 1922] introduces his inkblot test for the study of personality in *Psychodiagnostics*.

Frederick Hopkins discovers glutathione, a compound of three amino acids required for the utilization of oxygen by the cell.

Physique and Character by psychiatrist Ernst Kretschmer [b. Württemberg, Germany, October 8, 1888, d. Tübingen, Germany, February 8, 1964] suggests that the mental state of a person is related to his or her body build.

In Stockholm Carl Olof Nylen and Gunnar Holmgren introduce microsurgery using the operating microscope they invent.

⌘ Physics

Arthur Holly Compton [b. Wooster, Ohio, September 10, 1892, d. Berkeley, California, March 15, 1962] conjectures that ferromagnetism is owed to the rotation of an electron

around its own axis. *See also* 1907 PHY; 1935 PHY.

Alfred Landé [b. Elberfeld, Germany, December 13, 1888, d. Columbus, Ohio, October 30, 1976] introduces half-integer quantum numbers. The two previous quantum numbers known were assumed always to be integral (whole numbers). *See also* 1925 PHY.

Einstein wins the Nobel Prize for physics for discovery of the law of photoelectric effect. *See also* 1905 PHY.

I Tools

Playwright Karl Čapek coins the term *robot* from the Czech *robo-ta* ("slave labor") to describe the mechanical people in his play *RUR*. *See also* 1962 TOOL.

Canadian-American medical student John Augustus Larson [b. Shelburne, Nova Scotia, December 11, 1892, d. September 21, 1965] invents the polygraph (lie detector).

1922

▲ Archaeology

Howard Carter [b. London, May 9, 1874, d. London, March 2, 1939] on November 2 discovers the tomb and mummy of Pharaoh Tutankhamen [b. Egypt, reigned 1361 to 1352 BCE], familiarly known today as King Tut. *See also* 1894 ARCH.

Leonard Woolley [b. London, 1880, d. 1960] begins 13 years of excavations at Tell el Mukkayer (in Iraq). The ancient city he uncovers is usually considered to have been the Biblical Ur of Abraham.

★ Astronomy

Alexander Alexandrovich Friedmann [b. St. Petersburg, Russia, June 29, 1888, d. Leningrad (St. Petersburg), September 16, 1925], on the basis of Einstein's general theory of relativity, predicts that the universe must be expanding from a singularity — the big bang — improving on a similar prediction by Willem de Sitter and paving the way for a further revision by Lemaître. *See also* 1917 AST; 1927 AST.

⌘ Biology

Herbert MacLean Evans and Katherine Scott Bishop discover that rats fed a diet containing known nutrients and vitamins A and B are sterile. They begin reproduction when fed fresh lettuce as part of their diet. This experiment reveals that another vitamin, now called vitamin E, is needed for reproduction. *See also* 1920 BIO.

Archibald Hill of England and German-American biochemist Otto Fritz Meyerhof share the Nobel Prize for

physiology and medicine; Hill for his discovery of muscle heat production and Meyerhof for his discovery of oxygen-lactic acid metabolism. *See also* 1913 BIO.

□ Chemistry

On February 10, Jaroslav Heyrovský [b. Prague (Czech Republic), December 20, 1890, d. Prague, March 27, 1967] invents polarography, a delicate electrochemical system for measuring the concentration of ions in a solution. Soon after he designs the polarograph for automatic recording of curves that describe concentration of a solution and other characteristics. *See also* 1959 CHEM.

Francis Aston of England wins the Nobel Prize in chemistry for his discovery of isotopes with the mass spectrograph and related work with atomic masses. *See also* 1920 CHEM.

↳ Communication

Philo T. Farnsworth [b. Indian Creek, Utah, August 19, 1906, d. Holladay, Utah, March 11, 1971] describes to a teacher an electronic television system, which he had conceived of the year before. *See also* 1919 COMM; 1927 COMM.

FM (frequency modulated) radio is described in terms of the mathematics of waves by American mathematician John Renshaw Carson [b. Pittsburgh, Pennsylvania, June 28, 1886, d. October 31, 1940]. *See also* 1933 COMM.

⊕ Earth science

Victor Moritz Goldschmidt, pioneer Swiss-Norwegian geo-chemist [b. Zurich, Switzerland, January 27, 1888, d. Oslo, Norway, March 20, 1947] classifies

the elements into siderophile (iron-loving), lithophile (rock-loving), chalcophile (chalco-indicates copper but Gold-schmidt wanted to imply sulphur-loving), and atmophile (atmosphere-loving) elements. With this “geochemical periodic table,” he becomes the first to be able to predict the formation of specific minerals from specific combinations of elements and geological conditions.

Weather Prediction by Numerical Process by Lewis Fry Richardson [b. Newcastle, England, October 11, 1881, d. Kilmun, Scotland, September 30, 1953] gives equations for the prediction of rainfall and transfer of heat and moisture. The application of these will become practical after the invention of the computer. *See also* 1921 EAR.

The German *Meteor* oceanographic expedition, designed to recover gold from the oceans to pay Germany’s war debts (an unsuccessful enterprise), is equipped with sonar that can measure the depths of the oceans. *See also* 1925 EAR.

Σ Mathematics

Adolf Fraenkel improves the axioms of set theory developed by Ernst Zermelo by making it clearer how a set can be defined by a definite property. The Zermelo-Fraenkel axioms will become the standard foundation for virtually all systems of mathematics in succeeding years. *See also* 1908 MATH.

♥ Medicine & health

Elmer McCollum discovers vitamin D in cod liver oil and uses it for treating rickets. *See also* 1901 MED; 1923 MED.

Joseph Erlanger [b. San Francisco, California, January 5, 1874, d. St. Louis, Missouri, Decem-



Prince Louis-Victor Pierre Raymond de Broglie

[b. Dieppe, France, August 15, 1892, d. Paris, March 19, 1987]

Broglie’s doctoral thesis in 1924 explained that wave equations also apply to particles. Broglie showed that every material object is associated with a wave, most observable for small bits of matter, such as electrons. By 1926 Broglie’s waves, showing the predicted properties, had been found. Erwin Schrödinger used Broglie’s idea to create the wave equation for quantum mechanics and Max Born interpreted the waves as probabilities.

ber 5, 1965] and Herbert Spencer Gasser [b. Platteville, Wisconsin, July 5, 1888, d. New York, New York, May 11, 1963] adapt the cathode-ray oscilloscope for use in studying such functions of a single nerve fiber as speed of transmission of a message in different fibers. *See also* 1944 MED.

✿ Physics

Louis de Broglie derives a basic law of electromagnetic radiation (Wien’s law) based on considering light as particles with a given mass and momentum. *See also* 1893 PHY.

German-American physicist Otto Stern [b. Sohrau (Poland), February 17, 1888, d. Berkeley, California, August 17, 1969] and Walther Gerlach [b. Bierbach (Weisbaden, Germany), August 1, 1889, d. August 10, 1979] demonstrate the effect of an inhomogeneous magnetic field on neutral atoms and molecules. They establish that the atoms and molecules behave like tiny magnets as a result of the charges on the proton and electron. *See also* 1921 PHY.

Niels Bohr of Denmark wins the Nobel Prize for physics for discoveries in atomic structure and radiation. *See also* 1913 PHY.

1923

✿ Archaeology

L. Leland Locke proves that most of the Inca quipu (a.k.a.

quipu) record numbers. A quipu is a complex array of knotted strings. The quipu has long known to have been used for maintaining records. Locke determines that quipu indicate numbers in a decimal system using a form of place value, with some records being tens, some hundreds, some thousands, and so forth. *See also* 1997 ARCH.

★ Astronomy

George Ellery Hale invents the spectrohelioscope, a device that permits the image of the entire disk of the Sun to be observed at one wavelength of light and that can be used to measure velocities of gases in the solar atmosphere. The key is a rapidly oscillating slit that, because of persistence of vision, enables the viewer to see the whole solar disk.

Otto Struve, Russian-American astronomer [b. Kharkov, Russia, August 12, 1897, d. Berkeley, California, April 6, 1963] presents his first paper, on a spectrographic binary star, the beginning of over 900 published papers on astronomy. Struve will discover interstellar matter, thin clouds of gas and dust between the stars, and in 1952 argue that mechanisms for planet formation must be common around stars. *See also* 1995 AST.

✿ Biology

German biochemist Otto Heinrich Warburg [b. Freiburg-im-

Breisgau, Germany, October 8, 1883, d. Berlin-Dahlem, Germany, August 1, 1970] develops a method for studying respiration in thin slices of tissue. *See also* 1931 BIO.

Alfred Henry Sturtevant concludes that the direction in which a snail coils (clockwise or counterclockwise) is determined not by the coiling gene but by the direction of coiling in the snail’s mother. Thus, the direction is a result of the genes in the mother impressing a pattern on the egg.

✿ Chemistry

Dirk Coster [b. Amsterdam, Netherlands, October 5, 1889, d. Groningen, Germany, February 12, 1950] and György von Hevesy discover the element hafnium (Hf), named for the Latin version of Copenhagen, where the discovery is made.

Theodor H.E. Svedberg [b. Fleräng, Sweden, August 30, 1884, d. Stockholm, February 25, 1971] develops the ultracentrifuge, a device that spins so rapidly that it removes particles from colloidal suspensions. From the amount of time it takes to remove specific particles, it is possible to determine their molecular weights, essential in studying large organic molecules. *See also* 1926 TOOL.

Johannes Nicolaus Brønsted [b. Varde, Denmark, February 22, 1879, d. Copenhagen,

December 17, 1947] suggests that acids give up a hydrogen ion in solution and that bases accept a hydrogen ion in solution, virtually the modern concept of acids and bases. *See also* 1909 CHEM.

Fritz Pregl of Austria wins the Nobel Prize in chemistry for microanalysis of organic substances. *See also* 1909 CHEM.

Communication

Cable radio becomes available in Dundee, Michigan, for \$1.50 per month. *See also* 1948 COMM.

The vibraphone is invented in the United States. It is a form of xylophone that uses electrically powered resonators to affect the tone. *See also* 1931 COMM.

Earth science

Dutch geophysicist Felix Andries Vening Meinesz [b. The Hague, Netherlands, 1887, d. 1966] makes gravity measurements at sea using a pendulum aboard a submarine.

Electronics

On December 29 Vladimir Zworykin [b. Mourom, Russia, July 30, 1889, d. July 29, 1982] files a patent for an entirely electronic television camera tube, the iconoscope. *See also* 1922 COMM; 1925 COMM.

Energy

Seismic methods are used in Mexico for the first time to search for petroleum deposits; that is, explosions are set off and reflections of the waves they produce in Earth's crust are measured to determine what kind of rock is below the crust. *See also* 1900 ENER.

Mathematics

Stefan Banach [b. Krakow

(Poland), March 30, 1892, d. Lvov (Ukraine), August 31, 1945] generalizes the concept of a vector space to what comes to be known as an abstract Banach space. The elements can be any entities that can be multiplied with real or complex numbers. The other main criterion is that rules corresponding to a length for each vector must be followed. *See also* 1914 MATH.

Medicine & health

In Wisconsin Harry Steenbock [b. 1886, d. 1967] discovers that the ultraviolet component of sunlight increases the amount of vitamin D in food. He donates profits from the discovery to the University of Wisconsin, probably the first researcher to turn a patent over to a university. *See also* 1922 MED.

George Dick [b. July 21, 1881, d. October 10, 1967] and Gladys Dick [b. 1881, d. 1963], independently from Alphonse Dochez, find that scarlet fever is caused by streptococci. The Dicks develop an antitoxin for the disease.

Albert Calmette [b. Nice, France, July 12, 1863, d. Paris, October 29, 1933] and Camille Guérin [b. Poitiers, France, December 22, 1872, d. Paris, June 9, 1961] develop the tuberculosis vaccine BCG (Bacillus Calmette-Guérin). *See also* 1908 MED.

Walter Bradford Cannon suggests that shock is caused by blood draining into dilated capillaries and that treatment should mainly aim at returning normal circulation.

Sigmund Freud's *The Ego and the Id* describes ego as the conscious, rational level of the mind, powered by instinctual drives of the id and restrained

by societal demands internalized as the superego.

Sir Frederick Banting of Canada and John Macleod of England win the Nobel Prize for Physiology or Medicine for the discovery of insulin. *See also* 1921 MED.

Physics

Arthur Compton discovers the Compton effect: The wavelength of X and gamma rays increases when these waves (thought of as photons in this case) collide with electrons. The Compton effect also demonstrates the particulate nature of X rays. *See also* 1927 PHY.

Robert Millikan of the United States wins the Nobel Prize for physics for discovery of elementary electrical charge and for work with the photoelectric effect. *See also* 1913 PHY.

Tools

The Boston Wire Stitcher Company offers a simplified desk model stapler that is the

first to attain widespread popularity in offices. Soon after this staples will begin to be glued together in long rows, making them easy to insert and preventing the machines from frequent jamming. *See also* 1914 TOOL.

The big breakthrough for Gideon Sundback's Hookless No. 2 slide fastener comes when the device is used by B.F. Goodrich on its line of rubber galoshes. A Goodrich salesman names Hookless No. 2 the zipper, because he can close it and open it quickly (zip it). *See also* 1914 TOOL.

Transportation

Spanish inventor Juan de La Cierva [b. Murcia, Spain, September 21, 1895, d. in a crash at Croydon Aerodrome, near London, December 9, 1936] develops the basic idea of the autogiro. In addition to a wing, it has a freely rotating rotor that starts spinning when the aircraft gains speed and thus provides the lifting force.



BRITISH AIRMEN AND LA CIERVA'S AUTOIRO The British air command successfully tested the autogiro soon after its invention, although the craft did not see action in World War II. Most autogiros gained some lift and control in flight from stubby fixed wings, as this one is designed to do, but one model flew with no wings at all, making it look like a helicopter, although operating on very different principles.

This same year La Cierva completes several successful test flights. *See also* 1908 TRAN.

1924

► Anthropology

Raymond Dart [b. Brisbane, Australia, February 4, 1893, d. 1988] is given the skull of the Taung child, the first recognized fossil of an Australopithecine. Dart concludes that

the Taung child is a hominid that is not a human and not an ape. He names the species *Australopithecus africanus* and announces his discovery in 1925. *See also* 1894 ANTH; 1936 ANTH.

► Archaeology

Karel Absolon [b. Moravia (Czech Republic), June 16, 1877, d. October 6, 1960], who excavates Stone Age sites at Dolni Vestonice, Pavlov, and

Predmosti in Moravia throughout the 1920s, discovers the statuette known as the Venus of Dolni Vestonice, the oldest known fired ceramic ever found, dating from about 24,000 BCE. Other fired ceramics of various kinds, including many parts of animals, are also found at the Moravian sites. *See also* 25,000 BCE COMM.

★ Astronomy

Edwin Hubble demonstrates that the galaxies are true independent systems rather than parts of our Milky Way system by resolving the spiral arms of the Andromeda nebula into stars.

The *Henry Draper Catalog*, compiled by Annie Jump Cannon and listing 225,300 stars, is published by Harvard Observatory. *See also* 1911 AST.

The size of the universe

Many fuzzy patches of light were observed in the night sky after the introduction of better telescopes at the end of the 18th century. Such patches were termed nebulae ("clouds"). During the first decades of the 20th century, astronomers realized that many of the nebulae were huge systems of stars like ours (galaxies). This idea was not entirely new. The German philosopher Immanuel Kant wrote in 1755 in his book *General Natural History and Theory of the Heavens* that our solar system belongs to a flat, rotating system that is only one of the many other "island universes" that exist.

The discovery of "island universes" began in 1912, when American astronomer Henrietta Leavitt studied Cepheid variables in the Large and Small Magellanic Clouds, two particularly large patches seen in the southern skies that were easily resolved into stars. Cepheids are a type of variable star for which brightness is periodic over time, with the period depending on the star's size. By measuring the length of the period one can calculate the true brightness, or absolute magnitude, of these stars. From the true brightness, it is easy to determine their distance. Leavitt found that the Magellanic Clouds were well outside our own galaxy at a distance corresponding approximately to twice the diameter of our galaxy. In 1924 American astronomer Edwin Powell Hubble succeeded in observing Cepheid variables in the spiral nebula in Andromeda and in other spiral nebulae. By comparing the apparent and absolute magnitudes of these variable stars, Hubble was able to determine the distance to the nebulae. He found that they were much farther from our galaxy than even the Magellanic Clouds. Thus, this class of nebulae consisted of galaxies with sizes comparable to the Milky Way — after this discovery the word *nebula* gradually ceased to be applied to the galaxies.

Some years before this discovery, American astronomer Vesto M. Slipher had been studying the spectra of spiral nebulae (that

is, spiral galaxies). The spectrum of a star or galaxy not only discloses its chemical composition, but from the Doppler shift (a lengthening of wavelength — hence, also called the redshift) one can deduce its velocity relative to Earth. Such velocities had been expected to be randomly distributed. But when Hubble compared the distances of a number of galaxies with their redshifts, he made an astonishing discovery: The farther a galaxy the faster it is moving away from Earth. He also found that the recessional velocity is proportional to the galaxy's distance. This observation became the basis of the theory that the universe was created by a huge explosion and that the galaxies are the debris flying in all directions.

One of the first to propose that the universe was created by such an explosion was the Belgian priest Georges Lemaître. In 1927 he published a paper in which he showed that the concept of an expanding universe corresponds with the cosmological models based on Einstein's relativity theory, models introduced by Dutch astronomer Willem de Sitter and Russian mathematician Alexander Friedmann. Lemaître proposed that the universe had started by the explosion of a "primeval atom" — the concentration of all the mass of the universe in an extremely small space. A more detailed discussion of such an explosion and its consequences, developed in 1948 by George Gamow, Ralph Alpher, and Robert Herman, became known as the big bang theory.

The strongest confirmation of the big bang theory was the discovery in 1965 of cosmic background radiation by two physicists from Bell Telephone, Arno H. Penzias and Robert W. Wilson. While experimenting with a very sensitive microwave antenna, they discovered a hiss at a wavelength of 7.35 cm (2.89 in.) with an intensity that seemed independent of the orientation of the antenna. Such radiation had been predicted by Gamow. The hiss corresponds to radiation emitted by a body at a temperature of 3K (-270°C or -454°F), the temperature to which the universe is believed to have cooled as a result of its expansion since the big bang.



Edwin Powell Hubble

[b. Marshfield, Missouri, November 20, 1889, d. San Marino, California, September 28, 1953]

Hubble used Henrietta Leavitt's discovery of how to find distances with Cepheid variables to obtain in 1924 the distance to the Andromeda Galaxy (M31), showing that it is far outside the Milky Way. By 1929 he had found approximate distances to 18 galaxies and determined that the redshift of light from galaxies increases in a direct ratio to how far away they are. This effect is most easily explained as coming from the expansion of the universe, a concept that was entirely theoretical before Hubble's work. Hubble also developed the method still used for classifying types of galaxies — spiral, elliptical, irregular, and so forth.

Arthur Stanley Eddington formulates the mass-luminosity law for stars, relating the luminosity of a star to its mass. Eddington suggests that white dwarf stars are made up of degenerate matter in which the electrons have collapsed from their orbits, which is still believed to be true. *See also* 1914 AST; 1930 AST.

Biology

German zoologist Hans Spemann [b. Stuttgart, Germany, June 27, 1869, d. Freiburg-im-Breisgau, Germany, September 12, 1941] and Hilde Mangold [b. Gotha, Germany, 1898, d. 1924] show that if an amphibian embryo is grafted to another embryo, the graft is formed in part from tissue of the host, demonstrating "organizing action" by the second embryo. This is one of a series of experiments by Spemann that demonstrates that cells affect other cells near them. *See also* 1935 BIO.

Communication

Zenith produces its first portable radio for consumer use; it weighs 6.6 kg (14.6 lb), costs \$230, and fits into a suitcase. *See also* 1923 COMM; 1962 COMM.

Computers

The Computing Tabulating Recording Company becomes International Business Machines (IBM). *See also* 1896 COMP.

Earth science

Sir Edward Victor Appleton [b. Yorkshire, England, September 6, 1892, d. Edinburgh, Scotland, April 21, 1965] is the first to determine the distance to a remote object by radio ranging, a precursor of radar. He begins a series of experiments that locates the Heaviside Layer of the ionosphere at 100 km (60 mi) above Earth's surface. *See also* 1904 TOOL; 1931 TOOL.

Food & agriculture

International Harvester introduces the Farmall tractor, the first tractor with closely spaced front wheels, allowing it to be used in cultivating row crops and in making sharp turns at the ends of rows. *See also* 1908 FOOD; 1955 FOOD.

Schofield observes that cattle in Alberta, Canada, develop a mysterious internal bleeding disease after eating badly cured or spoiled clover hay, but the same hay when properly cured does not cause the disease. *See also* 1933 MED.

Materials

Urea-formaldehyde resins, common thermosetting plastics, are invented. Strength, heat and fire resistance, and insulating properties open the way to various applications, from doorknobs to electrical switchplates. *See also* 1909 MATR; 1926 MATR.

Medicine & health

Willem Einthoven of the Netherlands wins the Nobel Prize for physiology or medicine for his invention of the electrocardiograph. *See also* 1903 MED.

Physics

Louis de Broglie introduces particle-wave duality for matter: An electron or any other subatomic particle can behave either as a particle or a wave. His theory will be proven in 1927 by the electron diffraction experiment of Clinton Davisson. *See also* 1905 PHY; 1929 PHY.

Satyendra Nath Bose [b. Calcutta, India, January 1, 1894, d. Calcutta, February 4, 1974] introduces a new statistics for light-quanta (photons) and sends a copy of his work to Einstein. Einstein applies the Bose statistics to gases and

deduces that certain forms of matter should exhibit wave properties on a macroscopic scale. It will not be until 1995 that such matter, called Bose-Einstein condensate, will be created in the laboratory (although liquid helium, first made in 1911, also has Bose-Einstein characteristics). *See also* 1860 PHY; 1995 PHY.

Swedish physicist Karl Manne Georg Siegbahn [b. Örebro, Sweden, December 3, 1886, d. Stockholm, September 26, 1978], whose previous work with X rays includes developing methods to create X rays of varying wavelengths, becomes the first to refract X rays with a prism. Siegbahn wins this year's Nobel Prize for physics for X-ray spectroscopy.

Transportation

Henry S. Hele-Shaw [b. Essex, England, July 29, 1854, d. January 30, 1941] and T.E. Beacham develop the variable-pitch propeller for airplanes. It allows the propeller to be set for maximum efficiency for a given number of revolutions of the engine. Variable-pitch propellers will be generally adopted by aircraft manufacturers during the Second World War.

The Rocket into Interplanetary Space by Hermann Oberth [b. Hermannstadt, Transylvania (Romania), June 25, 1894, d. Nuremberg, Germany, December 28, 1989] is the first truly scientific account of space-research techniques. It is the first book to contain the notion of escape velocity (the speed necessary to escape the pull of gravity caused by a planet or other astronomical body). *See also* 1919 TRAN; 1926 TRAN.

1925

★ Astronomy

Vesto Slipher determines the radial velocities of 41 spiral nebulae (not yet recognized fully as galaxies) from their redshifts. He finds that several spirals are moving away from the Milky Way Galaxy at speeds too fast for them to be contained within our galaxy. *See also* 1920 AST.

Arthur Eddington concludes that the light and heat produced by stars originates from nuclear fusion. *See also* 1938 AST.

Biology

Statistical Methods for Research Workers by Ronald Aymler Fisher [b. London, February 17, 1890, d. Adelaide, Australia, July 29, 1962] becomes a standard work on statistical methods for genetics researchers.

The Scopes "Monkey trial" is held in Dayton, Tennessee; John T. Scopes [b. Paducah, Kentucky, August 3, 1900, d. Shreveport, Louisiana, October 21, 1970], a high-school teacher, is prosecuted and convicted for teaching evolution.

Chemistry

Walter Karl Friedrich Noddack [b. Berlin, Germany, August 17, 1893, d. Bamberg, Germany, December 7, 1960], Ida Tacke (later Ida Tacke Noddack) [b. Wesel, Germany, February 25, 1896, d. Bad Neuenahr, Germany, September 24, 1978], and Otto Berg discover the element rhenium (Re).

Robert Robinson [b. Rufford, England, September 13, 1886,

d. Great Missenden, England, February 8, 1975] locates the positions of all but one of the atoms in morphine. *See also* 1946 CHEM.

Communication

John Logie Baird [b. Helensburgh, Scotland, August 13, 1888, d. Bexhill, England, June 14, 1946] produces a television picture of a recognizable human face, with gray scales. *See also* 1923 ELEC; 1926 COMM.

Vladimir Zworykin files for a patent on a color television system. The patent is granted in 1928. *See also* 1926 COMM.

Astronomer Henri Jacques Chrétien [b. Paris, February 1, 1870, d. Washington, DC, February 6, 1956] invents the "anamorphic" objective lens. It compresses images laterally, allowing a wide picture to be recorded on narrow film; projection with a similar lens recreates the wide original image. This form of lens will be used from 1953 on for CinemaScope films. *See also* 1911 COMM; 1952 COMM.

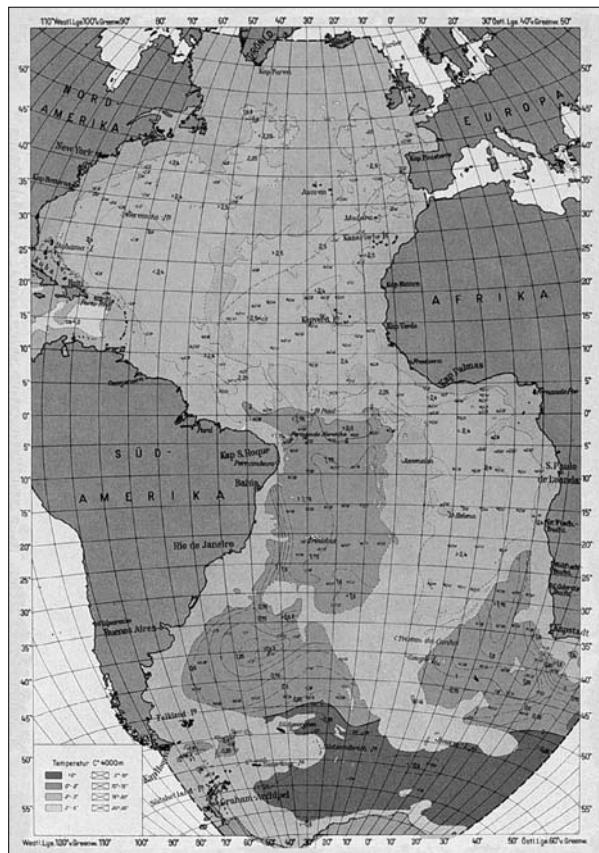
American Telephone and Telegraph and Western Electric jointly found the Bell Telephone Laboratories (now known as Bell Labs and part of Lucent Technologies) in New York, employing 3000 researchers. *See also* 1911 COMM.

Earth science

The German Meteor expedition, using sonar, discovers the mid-Atlantic ridge. *See also* 1922 EAR; 1953 EAR.

Ecology & the environment

Elements of Physical Biology by Alfred James Lotka [b. Lviv,



FLOOR OF THE ATLANTIC OCEAN When the *Meteor* expedition assembled its depth data, the compilation revealed an undersea mountain range running down the middle of the Atlantic Ocean. The mid-Atlantic ridge has an entirely different origin from such mountain chains as the Rockies or Andes — but that was not determined until decades after the discovery of the ridge. That the ridge followed the same curves as the continents on either side was one clue that led to the discovery of sea-floor spreading.

Austria (Lemberg, Ukraine), 1880, d. 1949] contains simple mathematical models for competition between species and predator-prey interactions, making it a serious attempt at mathematical biology. *See also* 1874 ECOL; 1926 ECOL.

Energy

Incandescent lamps with inside-frosted bulbs are introduced.

Food & agriculture

A wheel-type can opener is patented. It rides around the

rim of a can on a serrated wheel, similar to a common type of modern hand can opener (and a predecessor of the electric version in its mode of operation). *See also* 1870 FOOD.

Materials

Cemented carbides are introduced for use in cutting tools. These are metal carbides that are ground into small particles, mixed with cement, and then sintered (heated and formed into a solid without melting). In particular, tungsten carbide permits much

higher cutting speeds than previously. *See also* 1900 MATR; 1939 MATR.

♥ Medicine & health

James B. Herrick of Chicago becomes the first doctor to diagnose a heart attack in a

living patient. *See also* 1912 MED.

George H. Whipple publishes (with Frieda Robscheit-Robbins) the first of 25 papers on their experiments using diet to treat anemia in dogs, of which the second is the most

famous for its emphasis on the use of liver in the diet. *See also* 1918 MED; 1934 MED.

⌘ Physics

In January Wolfgang Pauli [b. Vienna, Austria, April 25, 1900, d. Zurich, Switzerland,

December 14, 1958] discovers the exclusion principle: Two electrons with the same quantum numbers cannot occupy the same atom. Application of this principle accounts for the chemical properties of the elements.

The quantum

One of the most important tools of science had its start in 1665 or 1666 when young Isaac Newton observed that a prism demonstrates that white light is a mixture of the colors of the rainbow. Although scientists realized earlier that the rainbow is formed when light is broken into different colors (the spectrum), Newton was the first to make a thorough study of the subject. Later, other scientists investigated this effect for light produced by heating different elements; from this investigation we learned of the composition of the stars. It is well known that study of the spectrum reveals the composition of a heated body or gas. Much less well known is that this study also reveals much about the atom.

The spectrum not only appears in the rainbow, it is hidden in another effect. An observation that must have been made in antiquity is that as iron is heated to forge it, it first becomes dull red, then brighter red, and gradually white. Other solid materials that do not burn behave much the same way. After formulation of the electromagnetic theory of light, theorists tried to explain this phenomenon from first principles. It was apparent that longer wavelengths appear at moderate temperatures. As temperatures rise, shorter and shorter wavelengths are emitted. When the material becomes white hot, all the wavelengths are represented. Studies of even hotter bodies — stars — showed that in the next stage the longer wavelengths drop out, so that the color gradually moves toward the blue part of the spectrum.

Efforts to make theoretical sense of the way the spectrum gradually appears and disappears were at first unsuccessful. For one thing, theory suggested that a perfectly black body — one that absorbs every wavelength of electromagnetic radiation equally well — would, upon heating, radiate every wavelength equally well. Experiments with simulated black bodies, however, showed that they behave in the same way that iron does when it is heated. In the 1890s Wilhelm Wien and Lord Rayleigh each tried to find a formula to explain these phenomena, but each failed in a different way. Wien's formula worked near the blue end of the spectrum and above, but failed for long wavelengths.

Rayleigh's formula was just the opposite, good for long wavelengths and not for short.

In 1900 Max Planck found an explanation that worked for all wavelengths, but little attention was paid to it. Planck made the assumption — which seemed quite odd at the time, even to Planck — that electromagnetic radiation could only be emitted in packets of a definite size, which he called quanta. People took notice of Planck's quantum only when Einstein, in 1905, used the idea to explain the photoelectric effect, to reconcile theory and experiment for heat, and to account for the propagation of light without relying on an "ether." It appeared that Planck's quanta went beyond theory and had a physical reality.

By 1911 Ernest Rutherford had established that the atom has a positive nucleus surrounded by orbiting electrons. Like the black-body problem, however, the theory of the atom did not match experiment. Electrons orbiting a nucleus should give off radiation constantly, resulting in the electron falling into the nucleus. But atoms do not give off that kind of energy and they are usually quite stable.

Niels Bohr turned to Planck's quantum to salvage the theory. The size of the quantum, based on a pure number called Planck's constant, could be calculated. Starting in 1913, Bohr calculated the quantum of the simplest case, hydrogen, in which a single electron orbits a proton. He showed that experiment and theory could be reconciled by saying that the quantum restricts the electron to particular orbits. For each counting number (1, 2, 3, ...) there is one permissible orbit. For a given electron, the orbit it was in could be assigned that number, called its quantum number. Bohr based his calculations on the lines that form the spectrum of hydrogen gas (when a pure gas is heated, the spectrum consists of discontinuous lines, not a full rainbow). Bohr explained the lines by saying the light is emitted when the electron changes from a higher quantum number to a lower one. Hydrogen does not display a continuous spectrum because the electron moves from orbit to orbit in "quantum jumps." More complex atoms were beyond direct calculations, but approximations indicated that the same approach was correct.

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But there were minor complications. Bohr's model explained the large lines in the spectrum, but these lines are broken into smaller lines, called the fine structure of the spectrum. In 1915 Arnold Sommerfeld introduced a second quantum number to explain the fine structure. This was based on the idea that orbits allowed to electrons are ellipses, not circles. Next, it was observed that since the spectrum is affected by a magnet — the Zeeman effect — there needs to be a third quantum number to account for the magnetic state of the electron. Finally, in 1925 George Uhlenbeck and Samuel Goudsmit found that electrons spin, necessitating yet another quantum number. Each number is an integer that describes the specific state of the electron. If you know that the numbers are, say, 3, 1, 1, 2, then you have a precise description of the electron in its orbit.

The discovery of spin was a major breakthrough, resulting in the rapid development of what is now known as the quantum theory. In 1925 Wolfgang Pauli determined that four quantum numbers is just right. Everything known about an electron in an atom can be reduced to the four numbers. Furthermore, no two electrons in an atom can have the same numbers. This Pauli exclusion principle, as it became known, accounts for how electrons are arranged in all atoms and tells why sulfur has different properties than tin.

About the same time, Werner Heisenberg found that arrays of quantum numbers could be used to calculate lines in the spectrum. This method of calculation is called the Heisenberg matrix mechanics.

Earlier, Louis de Broglie had proposed that every particle has a wave associated with it. Erwin Schrödinger used de Broglie's idea to calculate the spectral lines. Later it was shown that the Heisenberg matrix mechanics and the Schrödinger wave equation are equivalent.

In 1927 Heisenberg put forward the idea that it is theoretically impossible to determine the position and the momentum of an electron at the same time. The greater the degree of accuracy about one quantity the less the accuracy of the other. This uncertainty principle, as it is known, was later extended to other particles and other quantities. Max Born suggested that the Schrödinger equation could be interpreted as giving the probability that an electron is located in a particular orbit. This interpretation is still the most common in quantum theory.

Although Schrödinger's wave equation gives good results, they are not perfect. The wave equation does not take spin or the theory of relativity into effect. In 1928 Paul Dirac revised the equation to include spin and relativity. Dirac's theory was important because it revealed for the first time the existence of antimatter, but the mathematics is so complicated that physicists still use the Schrödinger wave equation. Dirac's theory essentially completed classical quantum theory.

After World War II, physicists developed quantum electrodynamics, a method of calculating the behavior of electrons and other particles that is even more precise than classical quantum theory.



Patrick Maynard Stuart Blackett

[b. London, November 18, 1897, d. London, July 13, 1974]

Blackett was awarded the 1948 Nobel Prize in physics for his development of methods for observing particle interactions. He was the first to photograph the transmutation of one element (nitrogen) into another (oxygen, after bombardment by an alpha particle) and the first to show matter (electrons and positrons) arising out of energy (gamma radiation). During World War II Blackett created the methods now known as operational research, which he used to improve greatly the ability of planes to sink submarines and to make research on radar and the atomic bomb more efficient.

Werner Karl Heisenberg

[b. Würzburg, Germany, December 5, 1901, d. Munich, February 1, 1976]

Heisenberg, with mathematical help from Max Born, developed in 1925 the first version of quantum mechanics, a matrix method of calculating the behavior of electrons and other subatomic particles. The method was superseded as a practical tool soon after by the more intuitive wave equation of Erwin Schrödinger, but matrix mechanics remains a great intellectual accomplishment. Heisenberg's most lasting contribution was his discovery in 1927 of the uncertainty principle, a foundation of quantum theory. A few years later he introduced a new quantum number called isotopic spin. Heisenberg continued to contribute to particle physics, introducing useful computational techniques in the 1950s.



In April P.M.S. Blackett starts his experiments colliding atoms in a Wilson cloud chamber, making the first photographs of nuclear interactions.

In July German physicist Werner Heisenberg publishes his first paper on quantum mechanics, showing how matrix algebra can be used to calculate results from theory that are in agreement with experiment. *See also* 1926 PHY.

In October Samuel Abraham Goudsmit [b. The Hague, Netherlands, July 11, 1902, d. Reno, Nevada, December 14, 1978] and Dutch-American physicist George Eugene Uhlenbeck [b. Djakarta, Indonesia, December 6, 1900, d. Boulder, Colorado, October 31, 1988] formulate the hypothesis of electron spin. *See also* 1926 PHY.

In November German-British physicist Max Born [b. Breslau (Wrocław, Poland), December 11, 1882, d. Göttingen, Germany, January 5, 1970], Werner Heisenberg, and Pascual Jordan [b. Hanover, Germany, October 18, 1902, d. Hamburg, Germany, August 1980] give a comprehensive treatment of matrix mechanics and recognize the concept of second quantization. *See also* 1954 PHY.

Clinton Joseph Davisson [b. Bloomington, Illinois, October 22, 1881, d. Charlottesville, Virginia, February 1, 1958] accidentally creates large nickel crystals that later will be used to exhibit electron diffraction, confirming Louis de Broglie's theories that particles always have waves associated with them. *See also* 1924 PHY; 1927 PHY.

Robert Millikan names cosmic rays and investigates how they are absorbed by the atmosphere and water in deep lakes. *See also* 1912 AST.

James Franck and Gustav Hertz of Germany win the Nobel Prize for physics for their discovery of the laws of electron impact on atoms. *See also* 1914 PHY.

→ Transportation

The world's first public road with entrances and exits rather than intersections, the Bronx River Parkway in New York City and Westchester County, opens. Since 1913 a total of 454 parcels of land had been acquired and 370 buildings torn down or moved to make room for the 25 km (15.5 mi) park and roadway planted with 30,000 trees and 140,000 shrubs. In some places, trees and shrubs are used to separate northbound and southbound lanes, another innovative practice at the time. *See also* 1940 TRAN.

1926

◀ Anthropology

Roy Chapman Andrews writes *On the Trail of Ancient Man* to describe his experiences in the Gobi Desert, where he finds no traces of ancient humans,

but does discover the first fossilized dinosaur eggs known to science, as well as other important fossil finds. *See also* 1995 EAR.

▲ Archaeology

A French team of engineers uncovers the body of the Sphinx from the desert sand as part of a restoration effort. Ironically, this speeds deterioration. *See also* 1401 BCE ARCH.

★ Astronomy

The Bruce Proper Motion Survey has its start. Photographic plates showing the same region of the night sky a quarter century apart are compared using a blink microscope to see which stars have moved relative to the others. The two plates are projected onto the same location and first one then the other is turned off. If a star or other object has moved between the times of the two images, it will appear to flicker from one location to another.

Bertil Lindblad [b. Örebro, Sweden, November 26, 1895, d. Stockholm, June 26, 1965] proposes a dynamical model of the Milky Way in which the center core rotates as a unit and the outer portions rotate more slowly. Later studies of other galaxies, however, will

suggest that the visible portion of a galaxy rotates with the same degree of angular velocity (implying that the galaxies are embedded in unseen dark matter). *See also* 1933 AST.

Edwin Hubble's "Extragalactic Nebulae" deals with galactic and extragalactic nebulae. It introduces his classification scheme for galaxies into spirals, ellipticals, barred spirals, and irregulars (he had hinted at this system as early as 1922). Hubble incorrectly assumes that one form evolves into others. *See also* 1924 AST.

Arthur Stanley Eddington's *The Internal Constitution of the Stars* is the first major work on stellar structure. Eddington uses the concept of radiation pressure from the interior of the star as one of the main factors involved in the luminosity. *See also* 1921 AST.

↗ Biology

Hermann Joseph Muller [b. New York, New York, December 21, 1890, d. Indianapolis, Indiana, April 5, 1967] discovers that X rays induce genetic mutations. He increases the mutation rate of fruit flies by a factor of 150 by irradiating them with X rays. *See also* 1910 BIO; 1946 BIO.

Roy Chapman Andrews

[b. Beloit, Wisconsin, January 26, 1884, d. Carmel, California, March 11, 1960]

Andrews became world famous as a fossil hunter in the 1920s, when he led four expeditions to Mongolia's Gobi Desert. His discoveries included *Protoceratops* bones and eggs; the first fossils of several dinosaur genera, including *Oviraptor* and *Velociraptor*; and evidence that Stone Age people lived in central Asia. Also a leading authority on whales, Andrews spent his entire professional career at the American Museum of Natural History, where he served as director from 1935 until his retirement in 1941.



Thomas Hunt Morgan's *The Theory of the Gene* is the culmination of finding the physical basis for Mendelian genetics based on breeding studies and optical microscopy; later advances will come from X-ray studies and molecular biology. *See also* 1911 BIO; 1933 BIO.

Endocrinologist Philip Edward Smith [b. De Smet, South Dakota, January 1, 1884, d. Massachusetts, December 8, 1970] demonstrates that removal of the pituitary gland (in a rat) causes other endocrine glands to cease functioning. *See also* 1902 MED; 1930 MED.

James Collip discovers parathormone, a hormone secreted by the parathyroid gland. *See also* 1914 BIO; 1960 BIO.

Chemistry

James Batcheller Sumner [b. Canton, Massachusetts, November 19, 1887, d. Buffalo, New York, August 12, 1955] crystallizes urease, the first enzyme to be crystallized, and establishes that it is a protein. *See also* 1907 BIO; 1946 CHEM.

Communication

John Logie Baird produces television images of moving objects using the Nipkow disk. He succeeds in transmitting pictures over telephone lines between London and Glasgow. The images are silhouettes. He also develops a television camera that uses infrared light to operate in the dark, which he calls noctovision. *See also* 1884 COMM; 1927 COMM.

Ecology & the environment

Konrad Lorenz [b. Austria, 1903, d. 1989] begins to devel-

op his theories on imprinting, a behavior first described by Oskar Heinroth [b. Kastel-bie-Mainz, Germany, March 1, 1871, d. May 26, 1945] in the early 1900s.

Vito Volterra conducts an extensive study of how to apply mathematics to biology; for example, he develops independently of Alfred James Lotka differential equations to describe predator-prey relationships. *See also* 1925 ECOL.

Materials

Hermann Staudinger [b. Worms, Germany, March 23, 1881, d. Freiburg-im-Bresgau, Germany, September 8, 1965] begins work that leads to the realization that plastics are all formed from long chains of small groups of atoms called monomers. In plastics, the monomers are joined together, so the material is said to be a polymer, or polymerized. *See also* 1924 MATR; 1954 MATR.

Willem Hendrik Keesom, Dutch physicist [b. Texel, Netherlands, June 21, 1876, d. Leiden, Netherlands, March 24, 1956] is the first to solidify helium. *See also* 1927 PHY.

Medicine & health

George Richards Minot [b. Boston, Massachusetts, December 2, 1885, d. Brook-

line, Massachusetts, February 25, 1950] and William Parry Murphy [b. Stoughton, Wisconsin, February 6, 1892, d. Brookline, Massachusetts, October 9, 1987] establish the use of liver in the diet as a successful treatment of anemia, based on earlier work with dogs by George Hoyt Whipple. *See also* 1925 MED; 1934 MED.

Arnold Lucius Gesell, American psychologist [b. Alma, Wisconsin, June 21, 1880, d. May 29, 1961] leads a group at Yale University that studies the stages of mental development of children, employing motion pictures to record the behavior of more than 12,000 children.

The Measurement of Intelligence by Edward Lee Thorndike [b. Williamsburg, Massachusetts, 1874, d. August 9, 1949] describes how to use tests to develop numerical measures of intelligence. *See also* 1905 MED.

Austrian endocrinologist Hans Hugo Selye [b. Vienna, Austria, January 26, 1907, d. Montreal, Canada, October 16, 1982] begins to develop his theory that stress can affect the physical functioning of the body.

Johannes Fibiger of Denmark wins the Nobel Prize in physiology or medicine for his dis-

covery of Spiroptera carcinoma. *See also* 1913 MED.

Physics

In January the first paper on wave mechanics by Erwin Schrödinger deals with the electron by applying Louis de Broglie's theory that electrons behave as waves. The theory is embodied by the Schrödinger equation. Later it will be shown that the Schrödinger equation method is equivalent to the Heisenberg matrix method, but most physicists follow Schrödinger, not only because they are more familiar with partial differential equations than with matrices, but also because the wave interpretation can more easily be visualized. *See also* 1924 PHY; 1933 PHY.

In February Enrico Fermi introduces Fermi-Dirac statistics, a mathematical treatment of particles that obey the exclusion principle of Wolfgang Pauli. This is equivalent to saying that they describe the behavior of collections of fermions (such as electrons and protons) as opposed to the Bose-Einstein statistics, which describe bosons (such as photons) and the Maxwell-Boltzmann statistics, which describe atoms or molecules in gases. *See also* 1925 PHY; 1928 PHY.

Erwin Schrödinger

[b. Vienna, Austria, August 12, 1887, d. Alpbach, Austria, January 4, 1961]

Schrödinger is known primarily as the creator of the wave equation for quantum mechanics, which he developed in 1926, just after Werner Heisenberg and coworkers had solved the same problems with matrix mechanics. Schrödinger's equation allows physicists to compute energy levels for electrons and remains an important tool in particle physics. After World War II Schrödinger considered fundamental problems in biology, expressing his views in the philosophical book *What Is Life?*





Enrico Fermi

[b. Rome, Italy, September 29, 1901, d. Chicago, Illinois, November 28, 1954]

Fermi was the only physicist of the 20th century whose experimental and theoretical work were equally valuable. After some important clarifications of Einstein's general theory of relativity, Fermi in the 1920s was the first to develop a mathematical treatment of how particles such as electrons — those that obey the Pauli exclusion principle, and now called fermions — interact physically. The topic was investigated independently by Paul Dirac and consequently called Fermi-Dirac statistics. Electrons in metals obey Fermi-Dirac statistics and Fermi's work is the basis of modern condensed matter physics. Fermi also studied the atomic nucleus, contributing to the theory of beta decay and showing experimentally that slow-moving neutrons can change one element or isotope into another (for which he received the 1938 Nobel Prize in physics). In 1942 Fermi was the chief designer of the first working nuclear reactor; it was based on several techniques that he developed to control nuclear fission in uranium.

In February Llewellyn Hilleth Thomas [b. London, October 21, 1903, d. Raleigh, North Carolina, April 20, 1992] completes the development of the concept of the spin of an electron by introducing a factor of two that had been missing in previous studies. *See also* 1925 PHY.

In June Max Born writes his first paper on the probability interpretation of quantum mechanics. *See also* 1952 PHY.

In August Paul Dirac relates symmetric, or even, wave functions of particles to Bose-Einstein statistics and antisymmetric, or odd, wave functions to Fermi-Dirac statistics. In a later interpretation, this means that the probability of even-wave particles being in the same place is always positive, but the probability of odd-wave particles being in the same place is zero. From this combination he also derives Planck's law from first principles. *See also* 1900 PHY.

In October Gilbert Lewis introduces the name *photon* for the light-quantum. *See also* 1905 PHY.

In November Eugene Paul Wigner [b. Budapest, Hungary, November 17, 1902, d. Princeton, New Jersey, January 1, 1995] introduces group theory into quantum mechanics. *See also* 1894 MATH; 1963 PHY.

John Desmond Bernal [b. Nenagh, Ireland, May 10, 1901, d. London, September 15, 1971] develops the "Bernal chart," an important tool for deducing the structure of a crystal from photographs of X-ray diffraction patterns. *See also* 1925 PHY; 1930 PHY.

Jean-Baptiste Perrin of France wins the Nobel Prize for physics for discoveries of the discontinuous structure of matter and equilibrium of sedimentation. *See also* 1908 PHY.

I Tools

Hans Busch of the University of Jena proves that magnets can act as a lens for electron waves, the theory behind the electron microscope. *See also* 1931 TOOL.

Theodor Svedberg wins the Nobel Prize in chemistry for his development of and work with the ultracentrifuge. *See also* 1923 CHEM.

→ Transportation

Robert Goddard launches the first liquid-fuel propelled rocket, which reaches a height of 56 m (184 ft) and a speed of 97 km (60 mi) per hour. *See also* 1924 TRAN; 1927 TRAN.

1927

◀ Anthropology

Davidson Black [b. Toronto, Canada, July 25, 1884, d. Peking (Beijing), China,

March 15, 1934] studies one of two hominid teeth found in 1921 in Zhoukoudian Cave near Peking (Beijing), China. He determines that the tooth belongs to a new species, which he names *Sinanthropus pekinensis*. This earliest discovery of "Peking man" later will be viewed as the discovery of a race of *Homo erectus* that lived in China. *See also* 1894 ANTH; 1929 ANTH.

★ Astronomy

Georges F. Lemaître [b. Charleroi, Belgium, July 17, 1894, d. Louvain, Belgium, June 20, 1966] proposes that the universe was created by the explosion of a concentration of matter and energy which he calls the "cosmic egg" or "primeval atom." His concept is the first version of the currently accepted big bang theory of the origin of the universe. *See also* 1922 AST; 1948 AST.

Paul Adrien Maurice Dirac

[b. Bristol, England, August 8, 1902, d. Tallahassee, Florida, October 20, 1984]

Dirac studied both engineering and mathematics before turning to particle physics. In 1928 Dirac set out to rework the basic wave equation of quantum mechanics so that Einstein's special relativity was taken into account. By 1930 he had created a new wave equation. Among other virtues, Dirac's equation accounted for spin, discovered experimentally in 1925 but without a theoretical basis at the time. The symmetry of Dirac's equation suggested that there must be a particle exactly like the electron, except with a positive instead of negative charge. An energetic photon would produce from its energy alone both the electron and its positive counterpart, the antiparticle. The predicted antiparticle, the positron, was observed in 1932 by Carl Anderson. Dirac's theory also predicted an antiparticle for every particle, which has since been found to be correct.



Dutch astronomer Jan Hendrik Oort [b. Franeker, Netherlands, April 28, 1900, d. Leiden, Netherlands, November 5, 1992] gives a dynamical proof that the Milky Way Galaxy has a spiral structure by measuring the velocity of stars. *See also* 1904 AST; 1951 AST.

Biology

Frank A. Hartman isolates “cortin” from the adrenal glands and suggests that Addison’s disease may be caused by the absence of it. Cortin is a mixture of hormones that has powerful effects on humans. *See also* 1935 BIO.

In a series of experiments that began in 1924, Corneille Heymans [b. Ghent, Belgium, March 28, 1892, d. Knokke, Belgium, July 18, 1968], working with his father, J. F. Heymans, determines that blood pressure in the aorta and the carotid arteries of the neck determines the rate of respiration. *See also* 1938 BIO.

Chemistry

Walter Heitler [b. 1900, d. 1954] and Fritz Wolfgang London [b. Breslau (Wrocław, Poland), March 7, 1900, d. Durham, North Carolina, March 30, 1954] demonstrate that a substantial fraction of the binding energy of the hydrogen molecule can be derived from the rules of quantum mechanics, providing a theoretical basis for explaining the covalent bond. *See also* 1919 CHEM; 1933 CHEM.

Communication

Ralph Vinton Lyon Hartley [b. Spruce, Nevada, November 30, 1888, d. May 1, 1970] introduces the concept of information as a measure for

the quantity of data in a message. *See also* 1938 COMM.

John Logie Baird transmits television pictures over a distance of 700 km (430 mi) over a telephone line between Glasgow and London. He also creates the first videodisk system, which records images in grooves on a conventional 78-rpm record. *See also* 1979 COMM.

On April 7 the American secretary of Commerce, Herbert Hoover, and Walter Sherman Gifford, president of AT&T, hold a conversation via the first picturephone known using television cameras and receivers equipped with Nipkow disks. The system allows transmission of pictures of people as they speak to each other over the telephone. *See also* 1884 COMM.

On September 27 Philo T. Farnsworth transmits the first all-electronic television image from one room of his laboratory to another. All previous television images had relied on mechanical means, usually the Nipkow disk. *See also* 1922 COMM; 1936 COMM.

On October 6 the movie *The Jazz Singer*, starring Al Jolson, introduces the era of talking motion pictures. *See also* 1920 COMM.

J.A. Neill improves magnetic sound recording by replacing the steel wire — used in the sound recorder invented by Valdemar Poulsen in 1898 — by a diamagnetic tape covered by a metallic layer, creating the tape recorder. Also, experiments with metal-powdered recording tape take place in Germany. *See also* 1898 COMM; 1931 COMM.

The AMI Corporation introduces the first jukebox with

electrical amplification and a choice of records (eight choices available). *See also* 1889 COMM.

The Schulz Player Piano Company introduces the Auto-typist, a typewriter that can produce multiple copies of the same document by using the basic mechanism of the player piano. The letters are punched into a paper roll. This is not the first typewriter to use a punched paper roll this way, nor will it be the last, but it is the version that makes the idea popular. Other similar typewriters are the Hooven Automatic (the first such machine), the Robotype of 1935, and the Flexowriter (introduced during World War II for use by the armed services). *See also* 1872 COMM.

Computers

Vannevar Bush [b. Everett, Massachusetts, March 11, 1890, d. Belmont, Massachusetts, June 28, 1974] and coworkers design an analog computer, the Product Integrator, to solve differential equations. The machine will later be built by one of Bush’s students. *See also* 1930 COMP.

Construction

Buckminster Fuller [b. Milton, Massachusetts, July 12, 1895, d. Los Angeles, California, July 1, 1983] moves to a Chicago slum and develops the Dymaxion house, a transportable dwelling suspended from a single mast. The house costs about the same as an automobile. *See also* 1935 TRAN.

Energy

French engineer Georges-Jean-Marie Darrieus [b. Toulon, France, September 24, 1888, d. 1979] in France patents a windmill with a vertical axle.

A working windmill will be built two years later with a rotor about 20 m (66 ft) high; it delivers 10 kW of electricity. *See also* 1883 ENER; 1929 ENER.

Materials

About this time chemist Richard Drew [b. 1886, d. 1956] of what is now the 3-M Corporation invents the first version of the cellophane tape that is familiar under its brand name as Scotch Tape. It goes on sale in 1928.

The “octane number,” a value associated with gasoline expressing its resistance against knock, is introduced. *See also* 1921 ENER; 1930 MATR.

Mathematics

Emmy Noether’s “Abstract Construction of Ideal Theory in the Domain of Algebraic Number Fields” becomes a cornerstone of modern abstract algebra and completes her earlier axiomatic treatment of abstract rings. *See also* 1905 MATH.

Medicine & health

Harvard engineers Philip Drinker [b. 1894, d. 1972] and Louis Agassiz Shaw [b. September 25, 1886, d. August 27, 1940] develop the iron lung, a device for mechanical artificial respiration.

(Antonio Caetano de Abreu) Egas Moniz [b. Avanca, Portugal, November 29, 1874, d. Lisbon, December 13, 1955] obtains X-ray pictures of the arteries of the brain by injecting a contrast medium (a chemical that shows up on X rays) into the blood vessels. *See also* 1897 MED.

Julius Wagner von Jauregg wins the Nobel Prize for physiology or medicine for the



THE IRON LUNG EVOLVES The original iron lung of Drinker and Shaw was made from an iron box and two vacuum cleaners — but it worked and evolved into the heavy tube seen at the left in this photo. A person inside the tube receives breathing assistance from changes in air pressure. By 1949 a light-weight version that a child could wear on the chest was becoming available. Today various light-weight aids to breathing, called ventilators, are available; many newer models push air into the lungs rather than pulling air in by lowering air pressure in the region surrounding the chest.

Louis de Broglie's hypothesis that subatomic particles behave like waves is confirmed by experiment. Clinton Davisson and, independently, George Paget Thomson [b. Cambridge, England, May 3, 1892, d. Cambridge, September 10, 1975] show that electrons can be diffracted by crystals. *See also* 1925 PHY; 1937 PHY.

Willem Hendrik Keesom, Dutch physicist, recognizes that there are two different phases of liquid helium, depending on the temperature. *See also* 1926 MATR.

Arthur Compton of the United States and Charles Thomson Rees Wilson of England share the Nobel Prize for physics, Compton for studies of the effect of wavelength change in X rays and Wilson for his cloud chamber. *See also* 1923 PHY; 1895 TOOL.

I Tools

In October American inventors Joseph W. Horton and Warren Alvin Morrison describe to the International Union of Scientific Radio Telegraphy their development of the first quartz crystal clock. Because of its piezoelectric effect, a quartz crystal controls the frequency of an electronic oscillator precisely, making it more accurate than any earlier timekeeper. *See also* 1944 TOOL.

Rolex introduces the first waterproof watch; it is called the "Oyster."

→ Transportation

Charles A. Lindbergh [b. Detroit, Michigan, February 4, 1902, d. Kipahulu, Hawaii, August 26, 1974] makes the first nonstop solo flight across the Atlantic Ocean from New York to Paris, France, in 33.5 hours.

fever treatment of some forms of paralysis using malaria inoculation to induce the fever. *See also* 1917 MED.

* Physics

Werner Heisenberg postulates his uncertainty principle, which says that it is impossible to determine completely two variables, such as position and momentum, of an electron simultaneously. In September Niels Bohr states the notion of complementarity, a philosophical concept that stems from ideas of quantum mechanics, notably the Heisenberg uncertainty principle. For example, Bohr suggests that energy and time are complementary — approaching one takes you farther from the other. *See also* 1925 PHY.



LINDBERGH AND HIS PLANE, THE SPIRIT OF ST. LOUIS Charles Lindbergh (left) stands in front of the small — 8.4 m (27 ft 8 in.) long — airplane with which Lindbergh made the first solo trip across the Atlantic in 1927, winning a \$25,000 prize for the first nonstop flight from New York to Paris. *The Spirit of St. Louis* was built by Ryan Airlines according to Lindbergh's specifications. Everything was done to cut down on weight, even eliminating the radio and parachute.

Using ideas about rockets and space from a 1924 book by Hermann Oberth, Verein für Raumschiffart ("the society for space travel") is founded in Germany. Among its early members are Wernher von Braun, who will later develop the first rockets to travel in space, and Willy Ley [b. Berlin, October 2, 1906, d. New York, June 24, 1969], who will write books that make rocket concepts easily understood by the average U.S. citizen. *See also* 1926 TRAN; 1931 TRAN.

1928

◆ Anthropology

Coming of Age in Samoa by Margaret Mead [b. Philadelphia, December 16, 1901, d. New York City, November 15, 1978] describes the passage from childhood to adulthood in a primitive society. *See also* 1930 ANTH.

▲ Archaeology

Dorothy Garrod [b. England, 1892, d. 1969] begins a six-year excavation of caves on Mount Carmel in Palestine, uncovering remains of the Natufian culture, the earliest practitioners of agriculture known at the time. *See also* 9000 BCE FOOD.

★ Astronomy

Edwin Hubble estimates that the Crab Nebula may be only 900 years old. *See also* 1758 AST; 1939 ast.

Henry Norris Russell determines the abundance of elements in the solar atmosphere by studying the spectrum of the Sun.

▲ Biology

British microbiologist Frederick Griffith observes that cer-

tain strains of bacteria acquire new characteristics that remain present in their offspring when grown in an extract from another strain possessing these characteristics. This shows that genetic information is transmitted by a chemical compound. *See also* 1952 BIO.

The Basis of Sensation by Edgar Douglas Adrian [b. London, November 30, 1889, d. London, August 4, 1977] is published. Adrian concludes that sensation caused by a stimulus of constant intensity progressively decreases for as long as the stimulation continues, even though signals of constant intensity travel the nerve. But the number of signals gradually decreases, resulting in the lowering of the sensation in the brain. *See also* 1932 BIO.

Hungarian-American biochemist Albert Szent-Györgyi [b. Albert Szent-Györgyi von Nagyrapolt, Budapest, Hungary, September 16, 1893, d. October 22, 1986] and Charles Glen King [b. Entiat, Washington, October 22, 1896, d. January 24, 1988] independently discover vitamin C. King has priority by two weeks. Neither succeeds in isolating the vitamin, which Szent-Györgyi names ascorbic acid. *See also* 1922 BIO; 1930 CHEM.

□ Chemistry

Hans Fischer [b. Höchstädt-am-Main, Germany, July 27, 1881, d. Munich, Germany, March 31, 1945] determines all of the atoms in heme, the part of hemoglobin that is not made from amino acids. *See also* 1930 CHEM.

German chemists Otto Diels and Kurt Alder [b. Königshütte, Silesia (Poland), July 10,

1902, d. Cologne, Germany, June 20, 1958] develop diene synthesis, more commonly known as the Diels-Alder reaction, a technique for combining atoms into molecules useful in forming many compounds. *See also* 1911 MATR; 1950 CHEM.

Sir Cyril Norman Hinshelwood [b. London, June 19, 1897, d. London, October 9, 1967], and independently Nikolay Nikolaevich Semenov [b. Saratov, Russia, April 15, 1896, d. September 25, 1986], show that below a certain temperature a mixture of hydrogen and oxygen gases is prevented from exploding by reactions with the walls of the vessel that contains the gases. *See also* 1956 CHEM.

DuPont chemist Thomas Midgley, Jr., working with Charles Franklin Kettering of General Motors, develops Freon as a gas for use in refrigerators. *See also* 1931 MATR.

◆ Communications

Bell Laboratories engineer Harold Nyquist formulates the "sampling theorem" named after him: If a continuous bandwidth-limited signal contains no frequency components higher than half the frequency at which it is sampled, then the original signal can be recovered without distortion. *See also* 1841 MATH.

On February 9 John Logie Baird demonstrates his television system by transmitting pictures across the Atlantic by radio from England to Hartsdale, New York. *See also* 1927 COMM.

A German producer of photographic materials, Agfa, invents a film for instantaneous development. The idea

will be extended by Edwin H. Land some 20 years later as the basis of his Polaroid camera. *See also* 1947 COMM.

On June 12 Ulises Armand Sanabria starts the first television broadcasts in Chicago, the first ever to transmit both picture and sound on the same wavelength. *See also* 1926 COMM; 1929 COMM.

On his radio station WRNY in New York City, Hugo Gernsback [b. Luxembourg, August 16, 1884, d. New York City, August 19, 1967], after encouraging listeners to build their own television sets using Nipkow disks, begins on August 21 to broadcast television, complete with program listings in the *New York Times*. The first day's programming features a fitness show, concerts, a cooking demonstration, and a lecture by Gernsback. Gernsback goes broke in 1929 and the whole operation is abandoned. *See also* 1884 COMM; 1936 COMM.

General Electric begins television broadcasts. *See also* 1927 COMM.

◊ Materials

Edwin Herbert Land [b. Bridgeport, Connecticut, May 7, 1909, d. Cambridge, Massachusetts, March 1, 1991] develops a transparent substance that polarizes light, which can be used as a camera filter, sunglasses, or in other ways.

Public concern about the dangers of radioactivity lead to the formation of the International Commission on Radiological Protection, an independent, nongovernmental body of experts.

Eugène Houdry [b. Domont, France, 1892, d. July 18, 1962]

develops a method of cracking crude oil using a silica-alumina catalyst. He obtains gasoline with octane numbers between 91 and 93. *See also* 1911 MATR.

S Mathematics

John von Neumann [b. Budapest, Hungary, December 3, 1903, d. Washington, DC, February 8, 1957] develops his minimax concept for game theory. *See also* 1944 MATH.

Richard von Mises [b. Lemberg, Austria, April 19, 1883, d. Boston, July 14, 1953] develops a philosophical

approach to probability theory in *Probability, Statistics and Truth*. *See also* 1931 MATH.

♥ Medicine & health

Alexander Fleming discovers penicillin in molds; its clinical use in therapy starts only in the 1940s, when Howard Florey and Ernst Chain further develop it and it is learned how to manufacture it in quantity. *See also* 1921 MED; 1940 MED.

Dutch radiologist Bernard Ziedses de Planes [b. 1902, d. 1993] develops a method using a moving X-ray source

that can keep a single plane of the patient's body in focus. This is a predecessor of the CT scan. *See also* 1896 MED; 1957 MED.

Greek-American George Papanicolaou [b. Coumi, Greece, May 13, 1893, d. Clinton, New Jersey, February 19, 1962] develops the Pap test for diagnosing uterine cancers. *See also* 1913 MED.

Charles Nicolle of France wins the Nobel Prize in physiology or medicine for his research on typhus. *See also* 1909 MED.

❖ Physics

George Gamow [b. Odessa, Russia, March 4, 1904, d. Boulder, Colorado, August 19, 1968] develops a theory of radioactive decay by emission of an alpha particle that contains the first ideas of electron tunneling, a quantum effect in which an electron "tunnels through" a barrier that would normally be impassable. Tunneling is a quantum effect equivalent to walking through a brick wall; one way to think of it is that a particle is also a wave that can reform on the other side of the potential barrier. *See also* 1911 PHY; 1957 PHY.

Antibiotics: "magic bullets" against disease

From antiquity people have tried to find substances that would cure disease or heal wounds. Most of the recipes called for exotic ingredients, such as eye of newt. Folk wisdom and early doctors occasionally knew of something that seemed to work some of the time — garlic, molds, herbs, even soil — but most of the time the substances were ineffective. This did not stop people from looking for what we now think of as "wonder drugs."

In the 16th century, Paracelsus advocated strong chemicals to cure disease, including mercury compounds and other poisons. At the end of the 19th century, medical researchers had identified several microorganisms responsible for diseases such as syphilis, anthrax, tuberculosis, and cholera. To observe these bacteria under the microscope, one had to stain them. German bacteriologist Paul Ehrlich began to search for dyes that might kill bacteria on the theory that such dyes could destroy bacteria without affecting animal cells. In 1907 he discovered that Trypan red, a dye that stains trypanosomes, the organisms that cause African sleeping sickness, also kills them. Ehrlich then started tests with arsenic compounds. His student Sahachiro Hata discovered in 1909 that one of these compounds, number 606, introduced in 1910 and trademarked as Salvarsan, kills the bacterium that causes syphilis. Ehrlich called these compounds "magic bullets" because they kill harmful pathogens without affecting the patient.

Unfortunately, very few new magic bullets for the treatment

of other infections were found during the next years. In 1932 German biochemist Gerhard Domagk discovered that a dye containing the sulfonamide radical, called Prontosil Rubrum, was effective against streptococcal infections. Strangely enough, Prontosil did not kill streptococci in the test tube, but did so when injected into a mouse. Domagk had not tested Prontosil on humans, but when his daughter contracted streptococcal blood poisoning by pricking herself with a needle, and was near death, Domagk injected her with Prontosil Rubrum and saved her life.

Chemists discovered that Prontosil changed in the body and produced a fragment called sulfanilamide, the active agent against certain bacteria. They then started looking for other compounds that would chemically resemble sulfanilamide and kill a wider range of bacteria. Several such sulfa drugs were found. They were effective against a series of diseases that formerly had been treatable only with difficulty.

Before then, however, scientists had learned that looking for inorganic compounds was not the best way to solve the problem. The strongest agents against microbes had always existed in nature, just as traditional healers believe. Louis Pasteur and Jules François Joubert observed in 1877 that anthrax bacilli are killed by bacteria from the air. They also knew that soil, which is filled with many harmless bacteria and fungi, does not harbor most disease-causing bacteria. Substances in soil, probably produced by common soil bacteria or fungi, seem to kill other bacteria. Searching for these substances might be more productive than searching for inorganic compounds that would do the same thing. After all, it was known that these substances in soil exist.

(continued on next page)

However, there are so many different substances in soil that no one tried this approach for many years.

In the meantime, Alexander Fleming was seeking such a substance in a different known source. Tears contain something that kills bacteria and causes no physical damage to the body. In 1922 Fleming isolated the substance lysozyme from tears. Although lysozyme kills bacteria, it has no medical application. But Fleming continued to work on the problem of killing bacteria. Quite by accident he found another substance in 1928. This substance was produced by a mold that had somehow landed on one of his cultures of staphylococcus. It was evident in a ring of dead bacteria around each speck of mold. John Tyndall had observed the same effect while investigating bacteria and molds on airborne dust in the 19th century, but had not pursued it.

Fleming investigated and found that the substance produced by the mold, which he named penicillin, killed some bacteria, but not others. In addition, the substance did not damage white blood cells. He published a report on penicillin and went back to other work. Howard Florey and Ernst Chain, who were both experimenting with lysozyme, turned their attention to penicillin when World War II started, hoping to isolate the substance for use against war wounds. They succeeded, and scientists at the U.S. Northern Research Laboratory in Peoria, Illinois, found strains of mold that could be grown in large tanks to produce the new drug in quantity. Penicillin saved thousands of lives in World War II and continues to be, in one form or another, one of the most powerful and useful antibiotics.

Shortly before Florey and Chain began to work with penicillin, the first scientist to search for antibiotics in soil had achieved success. René Jules Dubos discovered two antibiotics, gramicidin and tyrocidin, in a substance produced by a soil bacterium. But it was the success of penicillin that started many teams of scientists searching soil samples. In 1943 Selman A. Waksman found streptomycin, an effective antibiotic for some bacteria although somewhat toxic to humans. Benjamin Duggar and coworkers found Aureomycin, the first tetracycline, in soil samples the following year. Since then, a variety of antibiotics have been found in soil samples and produced by various fungi. Mild antibiotics have even been found in garlic. By analyzing the structures of antibiotics and how they work, scientists have created many synthetic antibiotics.

While antibiotics have greatly reduced the effects of infectious disease, their very success has led to the problem of resistant bacteria. Bacteria can easily exchange genetic material through structures called plasmids. If a few bacteria are resistant to a particular antibiotic, they soon pass this trait on to others. Frequent use of antibiotics and sulfa drugs has created resistant populations of many disease-causing bacteria. The effectiveness of sulfa drugs against some diseases dropped by 50 percent over a 20-year period. Consequently, the search for new antibiotics continues, since bacteria resistant to one antibiotic may not be resistant to another that works by a different mechanism.

Chandrasekhara Venkata Raman [b. Tiruchirappalli, India, November 7, 1888, d. Bangalore, India, November 21, 1970] discovers the scattering effect named after him. Raman scattering occurs when light, because of its particle nature, is scattered by molecules of matter. This effect can be used to determine what those molecules are. *See also* 1930 PHY.

Swiss-American physicist Felix Bloch [b. Zurich, October 23, 1905, d. September 10, 1983] proves that some electrons can pass through a crystalline array without being scattered. *See also* 1927 PHY.

Charles Ellis and W.A. Wooster show that beta radiation apparently does not obey the

law of conservation of energy. When a neutron emits an electron, the resulting proton and electron should have the same momentum, but careful measurements show that some of the momentum is missing. Later it will be shown that an unnoticed particle, the neutrino, is involved in beta radiation and that conservation of energy is not violated. *See also* 1930 PHY.

Paul Dirac develops an equation that combines the ideas of quantum mechanics with special relativity (the relativistically invariant equation of the electron). *See also* 1926 PHY; 1933 PHY.

Arnold Sommerfeld uses quantum mechanics to show that electrons in a conductor

behave as a degenerate gas (one that is so concentrated that the Maxwell-Boltzmann statistics no longer apply). Most electrons in a conductor cannot participate in conduction; only a few high-energy electrons are involved in conducting electricity. Today the border between the two types of electrons is called the Fermi level. *See also* 1926 PHY.

Sir Owen Richardson of England wins the Nobel Prize for physics for his work on the effect of heat on electron emission (the Edison effect). *See also* 1911 PHY.

The radiation counter devised by Hans Geiger is substantially

improved in collaboration with German physicist Walther Müller; subsequently, careful physicists refer to the device as a Geiger-Müller counter. *See also* 1908 TOOL.

→ Transportation

Paul Kollsman [b. 1900, d. 1982] develops the barometric altimeter. The radio beacon is also introduced for navigation. The combination makes instrumental flight possible. *See also* 1913 TRAN; 1942 TRAN.

1929

← Anthropology

Davidson Black, C. C. Young, and Wenzhong Pei, find two lower jaws of hominids at

Zhoukoudian Cave near Peking (Beijing), China, the second evidence of what comes to be known as Peking man. *See also* 1927 ANTH; 1937 ANTH.

■ Archaeology

Andrew Ellicott Douglass, in Arizona, carefully matches rings on ancient pieces of yellow, or Ponderosa, pine to develop dating from tree rings. He determines the date of an Anasazi site by using tree rings observed in artifacts from the site, thus establishing the science of dendrochronology. *See also* 1911 ARCH.

Ridgley Whiteman, a teenager, writes to the Smithsonian Institution about spear points he has found near Clovis New Mexico, the first discovery of stone tools made by early hunters from about 9000 BCE who soon populated much of North America. *See also* 1908 ARCH.

★ Astronomy

Edwin Hubble determines the distance of the Andromeda nebula (930,000 light-years) using Cepheid variables. Using the same method on other galaxies, Hubble establishes that the more distant a galaxy is, the faster it is receding from Earth (Hubble's law), confirming that the universe is expanding. *See also* 1912 AST; 1948 AST.

◆ Biology

Walter Vogt publishes the first "fate map" of a vertebrate embryo — a description of how cells move from their original positions in the early embryo to their ultimate destination.

Fritz Albert Lipmann [b. Königsberg (Kaliningrad, Rus-

sia), November 12, 1899, d. Poughkeepsie, New York, July 24, 1986] isolates adenosine triphosphate (ATP) from muscle tissue and elucidates its role: It forms the link between energy generation and energy utilization in the cell. *See also* 1937 BIO.

Adolf Friedrich Butenandt [b. Bremerhaven-Lehe, Germany, March 24, 1903, d. Munich, Germany, January 18, 1995] isolates estrone, a female sex hormone. *See also* 1927 BIO; 1931 BIO.

Clarence Cook Little, who created the first strain of inbred mice in 1906, starts a facility in Bar Harbor, Maine, to use inbred mice in the study of cancer and other aspects of the biology of mammals. The stock market collapse in October results in the laboratory turning to selling mice to other institutions to raise money. Later this will become one of the main activities of the institution, now named Jackson Laboratory. *See also* 1906 BIO.

□ Chemistry

Phoebus Levene discovers that a previously unknown sugar, deoxyribose, is found in nucleic acids that do not contain ribose. Such nucleic acids are now known as deoxyribonucleic acids, or DNA. *See also* 1909 CHEM; 1936 BIO.

William Francis Giauque [b. Niagara Falls, Ontario, May 12, 1895, d. Oakland, California, March 28, 1982] discovers that oxygen is a mixture of three isotopes, oxygen-16, oxygen-17, and oxygen-18, eventually resulting in abandonment of the oxygen-16 standard for atomic mass in 1961 and its replacement by

the carbon-12 standard. *See also* 1913 CHEM.

John Howard Northrop [b. Yonkers, New York, July 5, 1891, d. Wickenberg, Arizona, May 27, 1987] develops new techniques for crystallization of enzymes. He crystallizes trypsin this year and other enzymes in following years. *See also* 1926 CHEM; 1946 CHEM.

Sir Arthur Harden and Hans von Euler-Chelpin of Sweden share the Nobel Prize in chemistry for their research on sugar fermentation and the role of enzymes in it. *See also* 1905 BIO.

◆ Communication

The BBC starts experimental television broadcasts using John Logie Baird's system; 12 images per second are transmitted at a wavelength of 216 m. *See also* 1926 COMM; 1936 COMM.

Western Television, founded by Ulises Armand Sanabria, begins to market the first commercial television receiver, the Visionette. *See also* 1928 COMM.

□ Earth science

Motonori Matuyama [b. USA, Japan, October 25, 1884, d. Yamaguchi, Japan, January 27, 1958] shows that rocks of different strata have their magnetic fields reversed in some instances. He concludes that Earth's magnetic field reverses direction from time to time. *See also* 1906 EAR; 1963 EAR.

◆ Energy

German engineer Felix Wankel [b. Luhran, Germany, August 13, 1902, d. Heidelberg, Germany, October 9, 1988] patents a rotary internal combustion engine, although it will not be

until the 1950s that the Wankel engine becomes practical. *See also* 1957 ENER.

Georges Claude develops the first power plant to use the difference in temperature between the upper and lower layers of the ocean to generate electricity.

A. A. Griffith conducts experiments with a gas turbine for airplane propulsion. *See also* 1908 ENER; 1930 TRAN.

Finnish engineer S.J. Savonius patents a vertical-axis wind turbine, called an S-rotor. *See also* 1920 ENER; 1931 ENER.

Georges Darrieus erects a 19-m (63-ft) two-bladed windmill in France. *See also* 1927 ENER; 1931 ENER.

■ Food & agriculture

Arrturi Virtanen [b. Helsinki, Finland, January 15, 1895, d. Helsinki, November 11, 1973] observes the similarity of different fermentation processes, all of which begin with the decomposition of sugar in the presence of phosphates by various bacteria. He analyzes the chemical steps involved and reveals adaptive formation of enzymes in the process. *See also* 1945 FOOD.

◆ Materials

Boron carbide is discovered; it displaces carborundum (silicon carbide) as the hardest artificial substance. *See also* 1891 MATR.

◆ Medicine & health

Manfred J. Sakel [b. Nadvorana, Austria, June 6, 1900, d. December 2, 1947] introduces insulin shock for the treatment of schizophrenia and other mental disorders. *See also* 1937 MED.

German psychiatrist Hans Berger [b. Neuses, Germany, May 21, 1873, d. Jena, Germany, June 1, 1941] develops the electroencephalogram (EEG), a device for collecting and recording human brain waves.

Oswald Avery and coworkers at the Rockefeller Institute (Rockefeller University) discover C-reactive protein (CRP), a marker in blood for the total amount of inflammation in all the tissues of a person.

Werner Forssmann [b. Berlin, August 29, 1904, d. Schopfheim (Germany), June 1, 1979], using himself as a test patient, proves that a catheter inserted into the vein inside a person's elbow can be safely threaded into the heart where it can be observed on an X ray. *See also* 1956 MED.

Christiaan Eijkman of the Netherlands and Sir Frederick Hopkins of England win the Nobel Prize for physiology or medicine for their work with vitamins. *See also* 1897 MED.

* Physics

George Gamow introduces his "liquid drop" model of the

atomic nucleus of heavy elements. *See also* 1935 PHY.

Physicist Dmitri Skobeltsyn [b. St. Petersburg, Russia, November 24, 1892] notes that cosmic rays often occur in groups called showers. *See also* 1930 AST.

Hermann Klaus Hugo Weyl [b. Elmshorn, Germany, November 9, 1885, d. Zurich, Switzerland, December 8, 1955] formulates the concept of gauge invariance (that certain properties should not change if one changes the measurement tool, or gauge, or otherwise makes a symmetry transformation) and discovers that gauge invariance for particles implies charge conservation — in a closed system, the total charge cannot change. *See also* 1918 PHY.

Walther (Walter) Wilhelm Georg Bothe [b. Oranienburg, Germany, January 8, 1891, d. Heidelberg, Germany, February 8, 1957] develops the idea of using two Geiger counters at the same time to detect the direction of cosmic rays, an important technique in working with subatomic particles. *See also* 1954 PHY.

Paul Dirac introduces the notion of hole theory, incorrectly identifying a hole of negative energy in a sea of electrons with a proton. He later will correct this idea and predict the existence of antimatter. *See also* 1931 PHY.

Prince Louis de Broglie of France wins the Nobel Prize for physics for his discovery of the wave character of electrons. *See also* 1924 PHY.

→ Transportation

Edwin A. Link [b. 1904, d. 1981] develops the flight trainer/stimulator for training novice pilots safely. *See also* 1928 TRAN.

Robert Goddard launches the first instrumented rocket; it carries a barometer, a thermometer, and a small camera. *See also* 1927 TRAN; 1931 TRAN.

Hermann Oberth's *Wege zur Raumschiffahrt* ("way to space travel"), which describes the use of rockets for space travel, introduces the concept of the multistage rocket. *See also* 1927 TRAN.

1930

◀ Anthropology

Margaret Mead's *Growing up in New Guinea* tells of her research among primitive tribes in New Guinea. *See also* 1928 ANTH.

▲ Archaeology

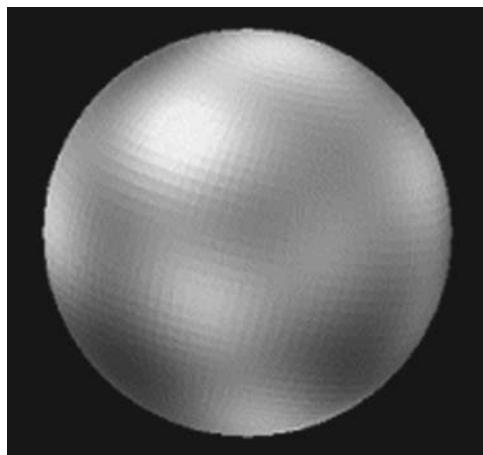
Clay tablets unearthed this year at Uruk and inscribed with some of the earliest form of writing known show no evidence of having been derived from pictographs, suggesting that writing may have had some different origin. *See also* 1738 COMM.

★ Astronomy

On February 18 Clyde William Tombaugh [b. Streator, Illinois, February 4, 1906, d. Las Cruces, New Mexico, January 17, 1997] discovers the planet Pluto. *See also* 1846 AST.

Subrahmanyan Chandrasekhar [b. Lahore, India, October 19, 1910, d. Chicago, Illinois, August 21, 1995] provides a theory for the existence of white dwarf stars and determines that a white dwarf can

PLUTO — STILL A MYSTERIOUS OBJECT When Clyde Tombaugh discovered Pluto, he saw only a point of light that moved among the stars. Pluto is so far away that the best images from the *Hubble Space Telescope*, such as this one, reveal only vague regions that are lighter or darker than their surroundings. Most astronomers today think Pluto should not be called the smallest planet but instead be labeled the largest of the Kuiper Belt Objects, strange bodies that are more like comets than asteroids.



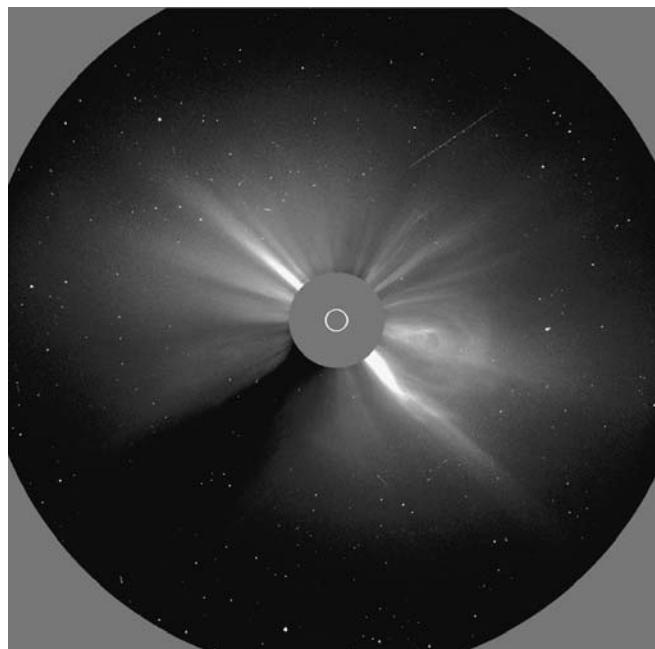
exist only if its mass is less than 1.44 times that of the Sun. This comes to be known as Chandrasekhar's limit. Arthur Eddington had earlier predicted white dwarf stars, but will disagree with Chandrasekhar on the details in a notable scientific argument of the 1930s, with Chandrasekhar generally seen as the winner. *See also* 1924 AST.

Swiss-American astronomer Robert Julius Trumpler [b. Zurich, Switzerland, October 2, 1886, d. Oakland, California, September 10, 1956] shows the existence of diffuse interstellar dust by studying its dimming effect on star clusters. As one consequence of the dust, the size of the Milky Way Galaxy is about three-fifths as big as previous estimates, which assumed that observed dimming was caused by distance. *See also* 1914 AST.

Bernard Ferdinand Lyot [b. Paris, February 27, 1897, d. on a train near Cairo, Egypt, April 2, 1952] builds the coronagraph, a special telescope in which a baffle stops the light from the solar disk and allows observation of the corona.

Bruno Benedetto Rossi, Italian-American physicist [b. Venice, Italy, April 13, 1905, d. Cambridge, Massachusetts, November 21, 1993], points out that cosmic rays should be deflected by Earth's magnetic field — to the east if positive and to the west if negative. Studies show the deflection to the east, establishing that most cosmic rays are positive. *See also* 1929 PHY; 1931 AST.

Russian-German optician Bernhard Voldemar Schmidt [b. Neissaar Island, Estonia, March 30, 1879, d. Hamburg, Germany, December 1, 1935] invents the corrector for a com-



CORONAGRAPH IMAGE OF THE SUN'S CORONA The basic idea of the coronagraph is blocking the image of the Sun's disk so that the extremely hot plasma that surrounds the Sun can be seen or photographed. This image is from LASCO, the Large Angle and Spectrometric Coronagraph on the SOHO space observatory, which orbits the Sun in the same path as Earth, but 1,500,000 km (930,000 mi) away. The Sun is behind the gray disk in the center; the bright streamers are the corona.

bined camera and telescope, producing a device that allows very wide-angle views with little distortion. The Schmidt telescope comes to dominate astronomy because it is free from coma, an aberration.

Chemistry

John Howard Northrup [b. Yonkers, New York, July 5, 1891, d. Wickenburg, Arizona, May 27, 1987] crystallizes the enzyme pepsin, an important step toward understanding the chemical nature of enzymes. *See also* 1926 CHEM; 1932 CHEM.

Arne Wilhelm Tiselius [b. Stockholm, Sweden, August 10, 1902, d. Uppsala, Sweden, October 29, 1971] introduces electrophoresis, a method for separating proteins in suspen-

sion using electric currents. *See also* 1938 CHEM; 1948 CHEM.

Albert Szent-Györgyi succeeds in isolating vitamin C from capsicum (peppers). *See also* 1928 BIO; 1933 BIO.

Hans Fischer of Germany wins the Nobel Prize in chemistry for his analysis of blood heme. *See also* 1928 CHEM.

Communication

Photoflash light bulbs are introduced for use in photography.

Computers

Vannevar Bush develops at MIT a prototype of the electromechanical analog computer, the Differential Analyzer, which can solve differential equations. He will

patent the idea in 1935 and a large Differential Analyzer will be built for use during World War II. *See also* 1927 COMP; 1936 COMP.

Construction

The Chrysler Building in New York City, at 319 m (1046 ft), briefly replaces both the Eiffel Tower and the Woolworth Building as the world's tallest structure, although it will soon be overshadowed by the nearby Empire State Building. *See also* 1913 CONS; 1931 CONS.

Construction starts on the Empire State Building in New York; it will be finished in 1931. *See also* 1931 CONS.

Earth science

Charles William Beebe [b. Brooklyn, New York, July 29, 1877, d. Simla Research Station, near Arima, Trinidad, June 4, 1962] and Otis Barton dive to 417 m (1368 ft) in their new submersible, the bathysphere, a hollow steel ball suspended by a cable. *See also* 1934 EAR.

Energy

The first heat pump, a kind of reversed refrigerator, is installed in the home of T.G.N. Haldane. *See also* 1852 ENER.

Food & agriculture

The Postum Company begins marketing frozen foods for the first time. *See also* 1917 FOOD.

Sliced bread is introduced by a baker in Battle Creek, Michigan. Inventor Otto Frederick Rohwedder had worked from 1912 until 1928 to develop a bread slicing machine — his final version not only slices the bread but also wraps the loaf, countering concerns that sliced bread would grow stale too quickly.

❖ Materials

Waldo L. Semon [b. Demopolis, Alabama, September 10, 1898, d. Hudson, Ohio, May 26, 1999] of the B.F. Goodrich Company invents polyvinyl chloride. I. G. Farbenindustrie in Germany develops polystyrene. About this time melamine resins (plastics) are also invented. See also 1926 MATR.

English physical biochemist William Thomas Astbury [b. Stoke-on-Trent, England, February 25, 1898, d. Leeds, England, June 4, 1961] discovers that wool has a different X-ray diffraction pattern when it is stretched. This leads him to use X-ray diffraction techniques to study the three-dimensional structure of proteins. See also 1925 PHY; 1934 BIO.

About this time lead begins to be added to commercially sold gasoline to prevent knocking. See also 1927 MATR.

Σ Mathematics

L. G. Schnirelman proves some number k exists such that every sufficiently large number is the sum of at most k prime numbers, but the proof yields no clues as to the value of k . This is a generalization of Goldbach's conjecture that every even number greater than two is the sum of two primes. See also 1742 MATH.

♥ Medicine & health

Bernardo Alberto Houssay, Argentinean physiologist [b. Buenos Aires, April 10, 1887, d. Buenos Aires, September 21, 1971] demonstrates that the pituitary gland produces a hormone that has the opposite effect from insulin, demonstrating the complexity of the endocrine system. See also 1926 BIO; 1968 MED.

Ernest H. Volwiler [b. Hamilton, Ohio, 1893, d. Lake Forest, Illinois, October 3, 1992] and Donalee L. Tabern [b. Bowling Green, Ohio, January 27, 1900, d. December 31, 1974] formulate Nembutal (pentobarbital sodium), a barbiturate used for inducing hypnotic sleep. See also 1863 MED; 1936 MED.

Karl Landsteiner of the United States wins the Nobel Prize for physiology or medicine for his definition of four human blood groups. See also 1902 MED.

⌘ Physics

The lambda point of helium, where liquid helium changes from one form (helium 1) to another (helium 2) is discovered. See also 1927 PHY; 1937 PHY.

Paul Dirac's *Principles of Quantum Mechanics* formulates a general mathematical theory in which matrix mechanics and wave mechanics are special cases.

Wolfgang Pauli proposes that an unknown particle (christened the neutrino by Enrico Fermi in 1932) accounts for the apparent violation of the law of conservation of energy in beta decay. See also 1928 PHY; 1932 PHY.

Isidor Isaac Rabi [b. Rymanów, Austria (Poland), July 29, 1898, d. New York City, January 11, 1988] develops a precise method of using beams of molecules to study the magnetic properties of atomic nuclei. He measures the rotation of atoms and molecules and determines such properties as the mechanical and magnetic moments of atomic nuclei. See also 1944 PHY.

Chandrasekhara Raman of

India wins the Nobel Prize for physics for his laws of light diffusion. See also 1928 PHY.

☒ Tools

Frits (Frederik) Zernike [b. Amsterdam, Netherlands, July 16, 1888, d. Naarden, Netherlands, March 10, 1966] invents the phase-contrast microscope, which reveals the structures of cells and tissues without staining, using instead the subtle differences in phase of light that passes through the material. See also 1953 TOOL.

✈ Transportation

British engineer Frank Whittle [b. Coventry, England, June 1, 1907, d. Columbia, Maryland, August 8, 1996] patents the jet engine, 11 years before an aircraft flies using jet power. See also 1680 TRAN; 1941 TRAN.

Engineer Cedric Bernard Dicksee [b. England, 1888, d. 1981] develops a diesel engine suitable for road vehicles; it is an 8.1 liter, six-cylinder engine that is installed in trucks. See also 1915 TRAN.

1931

▲ Archaeology

The American School of Classical Studies begins a project to restore the Agora, or main square, of ancient Athens, which continues until the 1950s.

★ Astronomy

Experiments by Karl Guthe Jansky [b. Norman, Oklahoma, October 22, 1905, d. Red Bank, New Jersey, February 14, 1950] with an improvised aerial, trying to locate sources of interference in radio telephone links, lead to the founding of radio astronomy. Jansky publishes his first results in 1932 and in 1933

finds that the radio emission definitely comes from the Milky Way. See also 1851 AST; 1937 AST.

Sir Harold Spencer Jones [b. London, March 29, 1890, d. London, November 3, 1960] determines an accurate value for the distance to the Sun from the orbit of 433 Eros as it passes near Earth.

Bruno Rossi demonstrates that cosmic rays are powerful enough to penetrate a meter (yard) or more into solid lead. See also 1930 AST; 1938 AST.

☛ Biology

Adolf Butenandt isolates androsterone, a male sex hormone. See also 1929 BIO; 1934 BIO.

Eloise B. Cram suggests that a parasite may change its host's behavior. Specifically, she notes that a certain nematode may cause a grasshopper it has infected to be an easier prey for chickens.

Swiss chemist Paul Karrer [b. Moscow, April 21, 1889, d. Zurich, Switzerland, June 18, 1971] establishes the structure and function of vitamin A. See also 1930 CHEM; 1937 CHEM.

Ulf von Euler [b. Stockholm, Sweden, February 7, 1905, d. Stockholm, March 9, 1983] discovers substance P, later recognized as a neurotransmitter. See also 1935 BIO.

Otto Warburg of Germany wins the Nobel Prize for physiology or medicine for his discovery of respiratory enzymes. See also 1923 BIO.

▷ Chemistry

Linus Pauling proposes that the phenomenon of resonance causes the stability of the benzene ring. See also 1865 CHEM.

Belgian-American chemist Julius Arthur Nieuwland [b. Hansbeke, Belgium, February 14, 1878, d. Washington, DC, June 11, 1936] develops neoprene, a synthetic rubber.

Harold Clayton Urey [b. Walkerton, Indiana, April 29, 1893, d. California, January 5, 1981] discovers deuterium, or heavy hydrogen, which has a nucleus that is a deuteron, a combination of a proton and a neutron. *See also* 1934 CHEM.

Communication

The first patent on stereophonic recording and reproduction of sound is issued. *See also* 1877 COMM; 1958 COMM.

Adolph Rickenbacker, Paul Barth, and George Beauchamp invent the electric guitar by attaching a microphone to the instrument and connecting it to an amplifier and loudspeaker. Their pickup is used on a steel guitar known as the Frying Pan. It is considered the first commercially viable electric guitar. *See also* 1940 COMM.

Construction

Othmar Hermann Ammann [b. Schaffhausen, Switzerland, March 26, 1879, d. New York, New York, September 22, 1965] designs and supervises construction on the 1067-m (3500-ft) George Washington Bridge over the Hudson River at New York City; its span is double that of the previous record holder for length.

The Empire State Building in Manhattan, New York City, is completed; with a height of 381 m (1250 ft), it is the world's tallest building until 1972. *See also* 1930 CONS; 1972 CONS.



Linus Pauling

[b. Portland, Oregon, February 28, 1901, d. Big Sur, California, August 20, 1994]

Pauling revolutionized the understanding of mineral structure, the formation of molecules, and the relation between molecule shape and chemical action. Early work on minerals — using atomic shapes and sizes to explain structure — presaged his better known analysis of chemical bonds. Pauling used quantum theory to analyze bonds from basic principles and applied this concept to determine characteristic structures in proteins. Such structures led to the lock-and-key theory of antibody action, provided Pauling's correct molecular explanation of sickle cell anemia, and inspired James Watson and Francis H.C. Crick to unravel DNA. In later years, Pauling championed large doses of vitamin C to combat colds and promote long life, but this theory remains controversial.



THE BRAND-NEW EMPIRE STATE BUILDING Although the building itself looks much the same today, it no longer dominates the skyline of midtown Manhattan quite the way it did in 1931, although it is once again the tallest building in New York City. Today various colored lights on the top floors are changed to mark holidays and special events.

Energy

Georges Darrieus patents a vertical-axis windmill of a type sometimes called an egg-

beater. The Darrieus rotor wind engine is reinvented in the 1970s in Canada. *See also* 1929 ENER; 1941 ENER.

Materials

DuPont and General Motors jointly form the Kinetic Chemical Corporation to introduce Freon, the first commercial chlorofluorocarbon. Freon is the trade name for the highly inert gas dichlorodifluoromethane, but similar gases developed later and used in refrigeration or as spray propellants are also called Freons. Much later Freons will be implicated as possible causes of destruction of the ozone layer that protects Earth from ultraviolet radiation. *See also* 1928 CHEM; 1974 ECOL.

Karl Bosch and Friedrich Bergius of Germany win the Nobel Prize in chemistry for their invention of high-pressure methods of chemical production. *See also* 1909 MATR; 1912 MATR.

Mathematics

Austrian-American mathematician Kurt Gödel proves that any formal system strong enough to include the laws of arithmetic is either incomplete or inconsistent. The proof is based on an axiomatic system of numbers taken to be equivalent to the natural

numbers. Gödel uses a complex system to assign a number to every statement derived from the axioms and establishes that a number (and therefore a statement) exists that cannot be derived from

the axioms if the axioms are consistent. If the unprovable statement is added to the axiom list, however, it will either be inconsistent with the previous axioms or create yet

another unprovable statement. *See also* 1938 MATH.

Richard von Mises's *Wahrscheinlichkeitsrechnung* ("mathematical theory of probability and statistics")

introduces the concept of sample space into probability theory. In a sample space, each possible outcome is represented as a point. *See also* 1928 MATH.

Kurt Gödel

[b. Brünn, Austro-Hungary (Brno, Czechoslovakia), April 28, 1906, d. Princeton, New Jersey, January 14, 1978]

Kurt Gödel as a young man was part of the important Vienna Circle of logicians. Although Gödel made many contributions to logic (including showing that every statement in the most basic form of logic can either be proved or disproved), and some to physics, his 1931 proof that any system that contains the arithmetic of natural numbers is either not complete or not consistent, known as Gödel's incompleteness theorem, is his most famous. When World War II started, Gödel and his wife emigrated to Princeton, where he had lectured in 1934. From 1935 to 1937 he proved that some important unproved hypotheses in logic were consistent with set theory, work later extended by Paul Cohen, who showed that taking the opposite of these hypotheses was also consistent with set theory. In the 1940s and 1950s, Gödel was close to Einstein and formulated a mathematical framework for Einstein's theories.



The limits of mathematics

From its inception in the 17th century, the calculus worked but its foundation was nearly inexplicable. In the 19th century, however, mathematics purged itself of the murkiness of many of the basic concepts of the calculus by providing a logical framework based on simple arithmetic and geometry. Mathematicians called the new foundation *rigor*. It seemed possible that by the end of the century the process of rigorization could reach completion. To accomplish this mathematics would need to be both consistent within itself and complete in the sense that everything provable could be proved. In a famous speech in 1900, the mathematician David Hilbert proposed 23 unsolved problems for 20th-century mathematics to handle. Proving the consistency of arithmetic with integers was problem number two on his list. A few years earlier, Hilbert himself had set geometry on a new foundation that is internally consistent provided that arithmetic is consistent.

Georg Cantor, the founder of set theory, had discovered 17 years earlier some unsettling problems that suggested that there were roadblocks in the way of Hilbert's goal, but Hilbert did not think they would be insurmountable. For one thing, Cantor's discoveries concerned contradictions — generally called paradoxes by mathematicians — in his own set theory. One of these contradictions came from Cantor's proof that for every set, there is a set with more members. The paradox occurs when one considers the set of all sets. How can there be another set with more members than that? Two years after Hilbert's speech, Bertrand Russell discov-

ered an even more devastating paradox: Is the set of all sets that are not elements of themselves an element of itself? Russell's paradox was so close to the heart of set theory that he, and others, made major revisions and restrictions in the theory in an effort to avoid it. Still, as long as the paradoxes were confined to the newly created set theory, they did not seem to affect arithmetic, now used as the foundation for both geometry and calculus.

In the 1920s Hilbert launched a major effort in collaboration with other mathematicians to prove that mathematics is consistent. His group, the Formalists, seemingly achieved large parts of their goals, but the price was too high. They had to assume ideas that were far more complicated than the ones they were trying to prove.

In 1931 Kurt Gödel ended many of the arguments and effectively halted the efforts of the Formalists. That year he proved what is now known as Gödel's incompleteness theorem: For any consistent axiomatic theory that is strong enough to produce the properties of natural numbers (1, 2, 3, . . .), there exists a statement whose truth or falsity cannot be proved (or else the system is inconsistent). In other words, mathematics is either inconsistent or incomplete so long as it is based on arithmetic.

Since Gödel's incompleteness theorem, other mathematicians have used methods similar to his to show specific examples of statements that cannot be proved from widely accepted sets of axioms that are supposed to underlie all of mathematics. Despite incompleteness, however, mathematics continues to progress. Some mathematicians think mathematics is even more interesting now that they know that it is not unlimited in scope.

Medicines & health

Ernest Goodpasture [b. Montgomery County, Tennessee, October 17, 1886, d. Nashville, Tennessee, September 20, 1960] grows viruses in eggs, which will make the production of vaccines, such as polio vaccine, for viral diseases possible. *See also* 1907 MED; 1948 MED.

★ Physics

In May Paul Dirac proposes the antiparticle of the electron (the positron). He suggests that there is a particle exactly like the electron but with a positive charge. *See also* 1932 PHY.

Walther Bothe and Wilhelm Becker bombard beryllium with alpha particles and discover a highly penetrating radiation that is not deflected by magnetic forces. James Chadwick will show in 1932 that this radiation consists of neutrons. Irène Joliot-Curie and Frédéric Curie will make a similar discovery. *See also* 1932 PHY.

I Tools

Ernest Orlando Lawrence [b. Canton, South Dakota, August 8, 1901, d. Palo Alto, California, 1958] develops prototypes of what will become the main particle smasher for subatomic particles as well as atoms and ions, the cyclotron. The beam consists of electrons (or other charged particles) that follow a circular path as small pushes build up high speeds for the particles, which are then directed at the target. A prototype 28-cm (11-in.) in diameter reaches an energy of 1,000,000 electron-volts. *See also* 1932 TOOL; 1939 TOOL.

Ernst August Friedrich Ruska [b. Heidelberg, Germany,

December 26, 1906, d. Berlin, May 30, 1988] discovers that a magnetic coil can focus a beam of electrons, creating the first crude electron microscope; it achieves a magnification of 400 power. The electron microscope is independently invented by Rheinhold Ruedenberg about the same time. *See also* 1933 TOOL.

British Post Office engineers observe that short-wave radio receivers are disturbed when aircraft fly within 6 km (4 mi) of the receiver but fail to take the necessary mental step that would convert this idea into radar. *See also* 1924 TOOL; 1935 TOOL.

→ Transportation

Johannes Winkler [b. Carlruhe, Germany, May 29, 1897, d. Braunschweig, Germany, December 27, 1947] makes the first European firing of a liquid-propelled rocket. *See also* 1927 TRAN.

1932

▲ Archaeology

Italian archaeologists and engineers drain Lake Nemi near Rome to recover two giant barges that had been built by Roman emperor Caligula. *See also* 50 CE TOOL.

★ Astronomy

American astronomer Theodore Dunham [b. December 17, 1897, d. April 3, 1984] discovers carbon dioxide in the atmosphere of Venus. Today astronomers recognize that carbon dioxide is the main component of the Venusian atmosphere, producing a runaway greenhouse effect that contributes to the planet's

high surface temperature. *See also* 1905 ECOL.

J.P. Schafer and W.M. Goodall report their discovery of reflections of radio waves by meteors. *See also* 1939 EAR.

❖ Biology

Hans Adolf Krebs [b. Hildesheim, Germany, August 25, 1900, d. Oxford, England, November 22, 1981] discovers the urea cycle, which transforms ammonia to urea in mammals (this is not the same as the famous Krebs cycle, which he will discover in 1937). *See also* 1935 BIO.

George Wald [b. New York City, November 18, 1906, d. Cambridge, Massachusetts, April 12, 1997] discovers that vitamin A occurs in the eyes of several species. *See also* 1933 BIO.

Swedish biochemist (Axel) Hugo (Teodor) Theorell [b. Linköping, Sweden, July 6, 1903, d. Stockholm, August 15, 1982] succeeds in isolating myoglobin crystals.

Problems of Relative Growth by Julian S. Huxley [b. London, June 22, 1887, d. London, February 14, 1975] contains the important rule in embryology stating that the specific growth rates of the organs of the body stand in constant ratios to each other. *See also* 1915 BIO.

Sir Charles Sherrington of England and Edgar Adrian of the United States win the Nobel Prize for physiology or medicine for multiple discoveries on the function of neurons. *See also* 1896 BIO; 1928 BIO.

▷ Chemistry

John Northrup crystallizes the enzyme trypsin. *See also* 1930 CHEM.

Irving Langmuir of the United States wins the Nobel Prize in chemistry for his study of monomolecular films. *See also* 1920 CHEM.

☛ Communication

Radio Corporation of America (RCA) demonstrates a television receiver with a cathode-ray picture tube, making experimental broadcasts from the Empire State Building in New York. *See also* 1923 ELEC; 1936 COMM.

⊕ Earth science

Carl-Gustav Arvid Rossby [b. Stockholm, Sweden, December 28, 1898, d. Stockholm, August 19, 1957] introduces the Rossby diagram, a method for plotting properties of air masses that becomes widely used. *See also* 1921 EAR.

⊗ Ecology & the environment

Max Kleiber [b. Zurich, Switzerland, January 4, 1893, d. 1976] devises what comes to be known as Kleiber's scaling law for organisms. Since the metabolic rate for individual cells of mass M varies according to a one-fourth power, or $M^{1/4}$ — that is, as the mass of cells changes by a factor of M , the rate of metabolism changes by $M^{1/4}$ — and since the number of cells in an organism is controlled by the volume of the organism, which varies as the third power of a linear dimension, metabolism for an entire organism varies as $M^{3/4}$. This rule is verified experimentally by examining the metabolism of varying organisms from tiny mice to giant elephants.

≡ Electronics

Guglielmo Marconi discovers that he can detect radio waves

of very high frequency, known as microwaves. The first application of such waves is radar about ten years later. *See also* 1921 ELEC; 1937 ELEC.

❖ Materials

The shape memory effect is discovered in an alloy of gold and cadmium. When the alloy is brought out of its original shape by bending, it returns to its original shape when heated. *See also* 1987 MATR.

♥ Medicine & health

German chemist Gerhard Domagk [b. Lagow (Poland), October 30, 1895, d. Burberg, Württemburg-Baden, West Germany, April 24, 1964] discovers the first sulfa drug, Prontosil. He finds it kills streptococci and is very effective against blood poisoning. *See also* 1908 MED; 1935 MED.

Armand Quick [b. Theresa, Wisconsin, July 18, 1894, d. January 26, 1978] introduces the Quick test to measure the clotting ability of blood.

The Wisdom of the Body by Walter Bradford Cannon describes his theory of homeostasis (the idea that the body tries to maintain a constant internal state).

⌘ Physics

James Chadwick discovers the neutron, which he announces first at the Kapitza Club at the Cavendish Laboratory and then more formally in a paper in the February 27 *Nature*.

Werner Heisenberg produces his first paper on nuclear forces in June. It introduces certain matrices as formal mathematical devices; these matrices eventually lead to the concept of isospin. Heisenberg proposes a model of the

atomic nucleus in which protons and the newly discovered neutrons are held together by exchanging electrons — an incorrect model, but one that would give rise to the more successful picture of the nucleus as held together by the exchange of medium-sized subatomic particles (now recognized as pions) of Hideki Yukawa. *See also* 1935 PHY.

Carl David Anderson [b. New York, New York, September 3, 1905, d. San Marino, California, January 11, 1991] discovers the positron (a positively charged electron and the first form of antimatter to be discovered) in cosmic-ray tracks, fulfilling a prediction by Paul Dirac. The first positron is observed in a photograph of cosmic-ray tracks on August 2. *See also* 1931 PHY.

Werner Heisenberg of Germany wins the Nobel Prize for physics for his discovery of quantum mechanics. *See also* 1925 PHY.

I Tools

John Cockcroft [b. Todmorden, England, May 27, 1897, d. Cambridge, England, September 18, 1967] and Ernest Thomas Sinton Walton [b. Dungarvan, Ireland, October 6, 1903, d. Belfast, Northern Ireland, June 25, 1995] become the first to use a particle accelerator to accelerate protons to bombard lithium, producing two alpha particles (commonly known as “splitting the atom”). The results are published on April 30, but experiments with the accelerator had begun as early as 1927. *See also* 1931 TOOL; 1951 tool

→ Transportation

An automatic pilot for aircraft is introduced for civilian use.

The autopilot uses air-driven gyroscopes to detect and correct deviations in headings or aircraft orientation. *See also* 1914 TRAN; 1941 TRAN.

The German General Staff hires astronomy student Werner von Braun [b. Wirzitz, Germany, March 23, 1912, d. Alexandria, Virginia, June 16, 1977] to undertake the development of rocket missiles. *See also* 1927 TRAN; 1934 TRAN.

Auguste Piccard [b. Basel, Switzerland, January 28, 1884, d. Lausanne, Switzerland, March 24, 1962] becomes the first human to enter the stratosphere. His balloon climbs to 16,201 m (53,153 ft). *See also* 1783 TRAN; 1948 TRAN.

1933

★ Astronomy

Fritz Zwicky [b. Varna, Bulgaria, February 14, 1898, d. Pasadena, California, February 8, 1974] discovers that 90 percent or more of the matter contained in galaxy clusters is dark matter, but few take notice at this time. *See also* 1926 AST; 1970 AST.

⌘ Biology

William Noburu Takahashi [b. August 14, 1905, d. 1987] and Thomas Ellsworth Rawlins [b. Elk Creek, California, November 13, 1895, d. Las Cruces, New Mexico, August 1, 1972] observe flow birefringence (double refraction caused by variation in refractive index with direction of flow) in sap from plants affected with tobacco mosaic virus, but not in sap from healthy plants. They propose that it is caused by the presence of rod-shaped virus particles, the first indication that viruses (which had

not yet been imaged) are tiny discrete bodies and not some form of fluid poison. *See also* 1898 BIO; 1935 BIO.

Tadeusz Reichstein [b. Włocławek, Poland, July 20, 1897, d. 1996] synthesizes ascorbic acid (vitamin C), which Walter Haworth also synthesizes independently in 1934. *See also* 1930 CHEM; 1934 CHEM.

George Wald determines that a chemical cycle involving vitamin A and another chemical is the basis of vision in the eye of a frog. *See also* 1932 BIO; 1967 BIO.

Thomas Hunt Morgan of the United States wins the Nobel Prize for physiology or medicine for his discovery of the relation of chromosomes to heredity. *See also* 1926 BIO.

❖ Chemistry

Hubert Maxwell James [b. 1908, d. 1986] and Albert Sprague Coolidge [b. 1894, d. 1977] calculate the strength of the covalent bond from the basic principles of quantum mechanics to a high degree of accuracy, demonstrating the close agreement of experiment and theory. *See also* 1927 CHEM; 1939 CHEM.

⌚ Communication

Franklin V. Hunt, John Robinson Pierce [b. Des Moines, Iowa, March 27, 1910, d. Sunnyvale, California, April 2, 2002] and J.A. Lewis introduce lateral engraving of sound records, which improves sound quality. *See also* 1931 COMM.

Edwin Armstrong patents wide-band frequency modulation, commonly called FM radio. Probably invented as early as 1931, FM radio will not be widely accepted until the late

1950s, although Armstrong himself will put together the first station with a regular broadcast schedule at Columbia University in New York City just before the United States enters World War II. Patent conflicts over FM will take all of Armstrong's considerable fortune and will not be completely settled — in Armstrong's favor — until after his death. *See also* 1906 COMM; 1941 COMM.

■ Construction

On September 8 work starts on the Grand Coulee Dam across the Columbia River, the largest concrete structure ever built; it is 168 m (550 ft) high and 1272 m (4173 ft) long. Its designer is John Lucian Savage [b. 1879, d. 1967], chief engineer of the U.S. Bureau of Reclamation. *See also* 1936 CONS.

❖ Ecology & the environment

The last known Tasmanian wolf dies in a zoo, although unverified reports of sighting of this marsupial in the Tasmanian jungle continue.

❖ Energy

High-intensity mercury vapor lamps are introduced. *See also* 1901 ENER.

❖ Materials

William Giauque and coworkers use a magnetic field to induce cooling in liquid helium to 0.25 K (0.25°C; 0.04°F above absolute zero). The magnetic field lines up molecules in a solid that is immersed in the liquid helium. When the field is removed, the energy needed to put the molecules back into their usual disarray comes from the helium, cooling the

helium even further. *See also* 1919 PHY; 1949 MATR.

Imperial Chemical Industries of Britain, utilizing basic research developed by Dutch chemist Antonius Mathias Johannes Michels [b. Amsterdam, Netherlands, December 31, 1889, d. Amsterdam, August 2, 1969], over a period of more than a dozen years, produces the first sample of the plastic polyethene. *See also* 1930 MATR.

♥ Medicine & health

The anticoagulant coumadin is recognized in spoiled clover hay by Karl Paul Link [b. Laporte, Indiana, January 31, 1901, d. Madison, Wisconsin, November 28, 1978], but purifying the actual chemical, which is an antagonist to vitamin K, will take until 1939. *See also* 1924 FOOD; 1939 MED.

✿ Physics

Germans Walther Meissner [b. Berlin, December 16, 1882, d. Munich, November 16, 1974] and Robert Ochsenfeld discover that a magnetic field is expelled from the interior of a superconductor (the Meissner effect or perfect diamagnetism). *See also* 1911 PHY.

Robert Jemison Van de Graaf [b. Tuscaloosa, Alabama, December 26, 1901, d. Boston, Massachusetts, January 16, 1967] develops a static electricity generator that can produce 7,000,000 volts.

In December Enrico Fermi explains beta-decay — the decay of an atomic nucleus produced when a neutron emits an electron (beta particle), becoming a proton. His theory includes the first suggestion of the existence of the weak interaction, one of the

four fundamental forces of particle physics. Fermi also includes the neutrino, a particle first proposed by Wolfgang Pauli, which is emitted along with the electron but at this time cannot be detected. *See also* 1930 PHY; 1934 PHY.

N. Marinesco and J.J. Trillat discover that photographic plates darken when submerged in water that is irradiated by ultrasound, discovering, but not recognizing, sonoluminescence caused by multiple bubbles produced by the high-frequency sound. *See also* 1934 PHY.

Paul Dirac of England and Erwin Schrödinger of Germany win the Nobel Prize in physics for their discoveries in wave mechanics. *See also* 1930 PHY; 1928 PHY.

☒ Tools

Ernst Ruska builds the first electron microscope that is more powerful than a conventional light microscope. He obtains a magnification of 12,000 power. *See also* 1931 TOOL; 1936 TOOL.

→ Transportation

American aviator Wiley Post [b. Texas, November 22, 1898, d. Point Barrow, Alaska, August 15, 1935] is the first to make a solo round-the-world airplane flight. It takes him seven days, 18 hours and 49 minutes. *See also* 1932 TRAN.

Russian aeronautics engineer and designer of manned space probes Sergei Pavlovich Korolev [b. Zhitomir, Ukraine, December 30, 1906, d. January 14, 1966] builds the first Soviet liquid-fuel rocket. *See also* 1931 TRAN.

1934

◀ Anthropology

Patterns of Culture by Ruth Fulton Benedict [b. New York City, 1887, d. New York City, 1948] is a classic of comparative anthropology that is based on her work with the Zuni and Hopi in the American Southwest.

★ Astronomy

Glass for the 5-m (200-in.) reflecting lens for the Hale telescope at Mt. Palomar Observatory is poured on December 2; a test and backup disk had been poured starting on March 25, a process taking 15 days just to fill the mold, followed by many days of controlled cooling. The Hale, when finished, will be the most effective telescope on Earth for more than 50 years. *See also* 1917 AST; 1936 AST.

Walter Baade [b. Schröttinghausen, Germany, March 24, 1893, d. Göttingen, Germany, June 25, 1960] and Fritz Zwicky discover that novas found in any galaxy are comparable in brightness, and that they differ from supernovas. They propose that neutron stars are formed during supernova eruptions, confirmed in 1968 when a neutron star is located in the debris of the July 4, 1054 supernova. *See also* 1968 AST.

Dutch-American astronomer Bart Jan Bok [b. Hoorn, Netherlands, April 28, 1906, d. Tucson, Arizona, August 5, 1983] shows that stellar associations (groups of hundreds of stars that are all relatively near each other) are young systems.

Astrophysicist Walter Grotrian

an [b. Aachen, Germany, 1890, d. 1954] discovers zodiacal dust (the cause of zodiacal light) by studying the spectrum of the solar corona. The dust is an extension of the solar corona beyond Earth's orbit that reflects sunlight, which produces a faint illumination (zodiacal light) that can sometimes be seen shortly before sunrise or soon after sunset.

Biology

Adolf Butenandt obtains the first preparation of progesterone, a female sex hormone, in pure form. *See also* 1931 BIO; 1939 CHEM.

John Bernal takes the first X-ray diffraction photograph of a protein crystal, pepsin. *See also* 1930 MATR; 1937 BIO.

György von Hevesy uses a radioactive isotope of phosphorus to study phosphorus

metabolism in plants. *See also* 1934 PHY; 1943 CHEM.

Chemistry

Walter Norman Haworth [b. Chorley, England, March 19, 1883, d. Birmingham, England, March 19, 1950] is among the first to synthesize vitamin C. *See also* 1933 BIO.

Arnold O. Beckman [b. Culom, Illinois, April 10, 1900] develops the pH meter, the first instrument that accurately measures the amount of acidity or alkalinity in a solution using electronic means. *See also* 1909 CHEM.

Harold Urey of the United States wins the Nobel Prize in chemistry for the discovery of heavy hydrogen. *See also* 1931 CHEM.

Earth science

William Beebe and Otis Barton set a depth record by diving to

1001 m (3038 ft) below the ocean's surface in a tethered sphere called a bathysphere. *See also* 1930 EAR; 1948 TRAN.

Ecology & the environment

Russian ecologist Georgii Frantsevich Gause [b. 1910] is the first to state the principle that two similar species cannot occupy similar ecological niches for long periods of time (known as Gause's principle).

Materials

Cambridge engineer Sir Geoffrey Ingram Taylor [b. London, March 7, 1886, d. June 27, 1975] explains that the ductility of metals comes from dislocations called line defects in the crystal structure of the metals. *See also* 1941 MATR.

Joseph Switzer [d. 1973] and Robert Switzer [b. 1914, d.

1997] invent the first fluorescent paint, which glows when illuminated by ultraviolet light, for use in Joseph's amateur magic act. Later they also develop colors that fluoresce in daylight, forming the Day-Glo Color Corporation in the 1940s to manufacture and market the paints and dyes. *See also* 1875 MATR; 1948 MATR.

Mathematics

Aleksander Osipovich Gelfand [b. 1906, d. 1968] and Theodor Schneider [b. 1911, d. 1988] show that an irrational power of an algebraic number (other than 0 or 1) is transcendental (not the solution of any algebraic equation), a feat that David Hilbert had predicted would come long after the proof of Fermat's "last theorem." Hilbert was, for once, wrong. *See also* 1900 MATH; 1936 MATH.

The Hale telescope at Mt. Palomar

As an individual object, the greatest technological achievement of the first half of the 20th century was just a big piece of glass, the mirror for the Hale telescope at Mt. Palomar in California. Although the Soviet Union tried to top it during the cold war, their slightly larger Zelenchuksaya telescope of 1976 came nowhere near the Hale reflector's cold perfection.

Astrophysicist George Ellery Hale is mainly remembered for his ability to put together financing and technical teams needed to produce large and effective telescopes. His first success, in 1897, was the world's largest refractor, the Yerkes telescope of the University of Chicago, with a 101.6-cm (50-in.) lens. Hale's next triumphs were a 152.4-cm (60-in.) reflector followed by a 254-cm (100-in.) reflector, both for Mt. Wilson Observatory in California. Each mirror in turn was the world's largest. In 1928 Hale proposed his greatest project in an article in *Harper's Magazine*, calling for a reflector of "200 inches or, better still, to twenty-five feet." But 25 feet (762 cm, or 300 in.) appeared

beyond the technological limits of the time, so Hale and his backers settled for 5 m (200 in.), only twice the diameter, four times the area, and eight times the volume of the then largest reflector.

The main problem in building the telescope was casting the glass mirror, although many other technical obstacles had to be surmounted as well. Several test castings in increasingly large sizes resulted in flawed pieces of Pyrex. The second full-sized mirror, however, proved to be flawless. It was transported from Corning, New York, to Pasadena, California, by rail at speeds of no more than 40 km (25 mi) per hour. It was ground and polished over the next decade, with time out for World War II. Final tests in 1948 revealed a tiny deviation in one section of the mirror, about equal to one wavelength of green light. Additional polishing resolved this last detectable problem.

The Hale telescope, known familiarly as Mt. Palomar, remained the greatest telescope on Earth until 1993, when the Keck 1 superseded it in size and resolving power. Even before that, the popular image of astronomy changed as the first great telescope in space, the Hubble Space Telescope, was launched in 1990.



THE BATHYSHERE BEING LOWERED INTO THE SEA The original idea for a vessel that could observe the deeper parts of the ocean came from Teddy Roosevelt, who suggested it to William Beebe over lunch. Beebe mentioned it to a journalist, and the press report led Otis Barton, who had a similar plan, to propose that he could fund building the vessel if Beebe's employer, the New York Zoological Society, would pay for the rest of the expedition. The successful vessel, the bathysphere ("sphere of the deep"), was one of the scientific marvels of the 1930s.

♥ Medicine & health

George Minot, William Murphy, and George H. Whipple of the United States win the Nobel Prize for physiology or medicine for the discovery and development of liver treatment for anemia. *See also* 1926 MED; 1925 MED.

⌘ Physics

The team of French physicist Frédéric and Irène Joliot-Curie develop the first artificial radioactive elements, a radioactive form of phospho-

rus formed by bombarding aluminum with alpha particles and radioactive nitrogen produced in the same way from boron. *See also* 1934 BIO.

In January Louis de Broglie introduces the general term *antiparticle* to describe the partner to a subatomic particle, a partner indicated by the second solution to the Dirac equation. For example, the positron, identical to the electron except for charge, is the antiparticle of the electron, so its other name is antielectron. Wolfgang Pauli

and Victor Frederick Weisskopf [b. Vienna, Austria, September 19, 1908, d. Newton, Massachusetts, April 21, 2002], independently of de Broglie, also demonstrate that subatomic particles must have antiparticles (not very many particles were known at this time, and the demonstration is largely overlooked). *See also* 1931 PHY; 1955 PHY.

Marcus Laurence Oliphant, Australian physicist [b. Adelaide, Australia, October 8, 1901, d. Canberra, Australia,

July 14, 2000], working with Ernest Rutherford, creates samples of tritium, the radioactive isotope of hydrogen, by bombarding heavy water (deuterium) with deuterons (particles composed of a single proton and a single neutron).

Tritium contains two neutrons and one proton. The new form of hydrogen is recognized by Luis Alvarez. *See also* 1931 CHEM.

Enrico Fermi suggests that slow, or thermal, neutrons can be used to split atoms. *See also* 1938 PHY.

Pavel Cherenkov [b. Voronezh, Russia, July 15, 1904, d. January 6, 1990] discovers that when a particle traveling close to the speed of light passes through a liquid or transparent solid, it emits light. This phenomenon occurs when the velocity of the particle is greater than that of light in the medium. This is known as the Cherenkov effect. *See also* 1937 AST.



Hans Bethe

[b. Strasbourg, France, July 2, 1906]

Bethe's work has permeated modern physics and astrophysics. His early work on nuclear reactions in the 1930s explained how stars produce energy by nuclear fusion. In 1947 Bethe was among the several founders of quantum electrodynamics. All in all, he performed theoretical work in all the major branches of physics and over a very long working life was able to synthesize his own work with that of others in articles that became standard references.



Irène Joliot-Curie

[b. Paris, September 12, 1897, d. Paris, March 17, 1956]

Frédéric Joliot-Curie

[b. Paris, March 19, 1900, d. Paris, August 14, 1958]

The Joliot-Curie husband-and-wife team found a way to create radioactive isotopes of elements whose common isotopes are stable, beginning with radioactive phosphorus. These artificial isotopes have become the main sources of radioactivity for medicine and industry.

Hans Bethe and Rudolph Peierls [b. Berlin, June 5, 1907, d. Oxford, England, September 19, 1995] show that the probability of interaction of neutrinos with matter is extremely small. *See also* 1933 PHY; 1965 AST.

James Chadwick and Austrian-American physicist Maurice Goldhaber [b. Lemberg, Austria, April 18, 1911] measure the mass of a neutron and find it to be greater than the mass of a proton plus an electron, which suggests (incorrectly) that neutrons are truly elementary particles. *See also* 1932 PHY.

Two physicists at the University of Cologne, H. Frenzel and H. Schultes, discover sonoluminescence: They observe a characteristic glow in water when it is irradiated with sound waves. There is little interest in the phenomenon until the 1990s. *See also* 1933 PHY.

→ Transportation

Wernher von Braun and his staff in Germany successfully launch their first rocket powered by alcohol and liquid oxygen, the A2 series. It achieves a height of 2.4 km (1.5 mi). *See also* 1932 TRAN; 1936 TRAN.

The first streamlined car to be offered to the public, the Chrysler Airflow, designed by Carl Breer, is introduced. Despite its rounded profile and fenders, it is not a commercial success. *See also* 1935 TRAN.

1935

生物学

Albert Szent-Györgyi locates four acids involved in respiration of muscle cells, the beginning of the discovery of the

citric-acid, or Krebs, cycle (completed by Hans Adolf Krebs). *See also* 1937 BIO.

Wendell Meredith Stanley [b. Ridgeville, Indiana, August 16, 1904, d. Salamanca, Spain, June 15, 1971] purifies and crystallizes tobacco mosaic virus (TMV). *See also* 1933 BIO; 1436 BIO.

Hugo Theorell shows that the coenzyme for an enzyme involved in respiration has a structure like that of vitamin B₂.

Henrik Dam [b. Copenhagen, Denmark, February 21, 1895, d. Copenhagen, April 1976] discovers vitamin K. *See also* 1933 MED; 1943 BIO.

William Cumming Rose [b. Greenville, South Carolina, April 4, 1887, d. September 25, 1984] discovers threonine, the last of the essential amino acids to be found. *See also* 1907 BIO; 1937 BIO.

Edward C. Kendall studies the cortical hormones from the adrenal cortex and isolates one of them that later becomes known as cortisone. *See also* 1927 BIO; 1936 BIO.

Ulf von Euler discovers the neurotransmitters prostaglandin and vesioglandin. *See also* 1931 BIO; 1942 BIO.

German biochemist Rudolf Shoenheimer [b. Berlin, May 10, 1898, d. September 11, 1941] is the first to use isotopes of elements that naturally occur in the body as a tracer; specifically, he uses deuterium (heavy hydrogen) to trace fat storage and metabolism. *See also* 1913 CHEM.

Hans Spemann of Germany wins the Nobel Prize for physiology or medicine for his discovery of the “organizer

effect” in embryonic development. *See also* 1924 BIO.

Chemistry

Croatian-Swiss chemist Leopold Ružička [b. Vukovar (Yugoslavia), September 12, 1887, d. 1976] finds the structure of testosterone, a male sex hormone. *See also* 1924 BIO; 1939 CHEM.

Frédéric and Irène Joliot-Curie of France win the Nobel Prize in chemistry for their synthesis of new radioactive forms of elements. *See also* 1934 PHY.

Communication

Kodak introduces the Kodachrome process of color photography. *See also* 1912 COMM; 1936 COMM.

International Business Machines (later IBM) introduces its version of the electric typewriter, which becomes a leader in offices. *See also* 1902 COMM; 1961 COMM.

German leader Adolf Hitler uses taped magnetic recordings to broadcast his speeches. Because of the absence of the characteristic periodic noise of recordings on disks, these speeches sound live over the radio. *See also* 1931 COMM.

Earth science

Charles Francis Richter [b. Hamilton, Ohio, April 26, 1900, d. Pasadena, California, September 30, 1985] develops a scale for measuring the strength of earthquakes based on the heights of waves in seismograms. It is still known as the Richter scale. *See also* 1900 EAR.

William Maurice Ewing [b. Lockney, Texas, May 12, 1913, d. Galveston, Texas, May 4,

1974] starts the seismic study of the sea bottom using refraction of waves caused by explosions. *See also* 1953 EAR.

Food & agriculture

The first combine that can be operated by a single person is introduced in the United States. *See also* 1910 FOOD.

Materials

Wallace Hume Carothers [b. Burlington, Iowa, April 27, 1896, d. Philadelphia, Pennsylvania, April 29, 1937] patents nylon, which he invented in 1934 (although its roots at DuPont de Nemours and Company, where Carothers worked, go back to a program started in 1927). *See also* 1938 MATR.

Basil Adams and Eric Holmes synthesize a number of resins from coal that can be used to remove salts of all kinds from water. Such synthetic materials are known as ion-exchange resins. *See also* 1955 MATR.

Medicine & health

Gerhard Domagk uses the first sulfa drug, Prontosil, on his youngest daughter to prevent her death from a streptococcal infection, the first use on a human being. Its success in this and other instances make Prontosil famous worldwide as the first “wonder drug.” *See also* 1932 MED; 1936 MED.

Physician John Heysham Gibbon [b. Philadelphia, Pennsylvania, September 29, 1903, d. February 5, 1973] and his wife Mary Gibbon Lovell [b. 1906, d. 1986] develop the first prototype of the heart-lung machine.

Alexis Carrel, working with Charles A. Lindbergh, develops a perfusion system that is intended for use in keeping

blood oxygenated during surgery. Lindbergh develops the actual pump. In practice, although the device is hailed as an "artificial heart" at the time (on the cover of the July 1 *Time*, for example), the pump is only used to demonstrate the principle with animal organs. *See also* 1914 MED; 1951 MED.

Egas Moniz develops pre-frontal lobotomy as a treatment for mental illness. *See also* 1891 MED; 1949 MED.

John Peters is the first to suggest that there must be some mechanism in or near the heart that acts as a blood pressure sensor and that can adjust the blood volume. It will be more than 40 years before the mechanism is discovered. *See also* 1981 MED.

❖ Physics

In November Hideki Yukawa [b. Tokyo, January 23, 1907, d. September 8, 1981] proposes that an undiscovered particle, which in 1939 will be named a meson ("middle-sized particle"), causes the attraction between nucleons (protons and neutrons in the atomic nucleus). He suggests that this "exchange particle" might have a mass equivalent to about 200 electrons. *See also* 1937 PHY.

P.M.S. Blackett shows experimentally that energy can be converted to matter by finding a gamma ray that spontaneously changes into an electron and a positron. *See also* 1905 PHY; 1948 PHY.

Soviet Lev Davidovich Landau [b. Baku (Azerbaijan), January 22, 1908, d. Moscow, April 1, 1968] publishes a mathematical explanation of the behavior of atomic magnets, clarify-

ing ferromagnetism. *See also* 1921 PHY.

Hans Bethe and Carl Friedrich von Weizsäcker [b. Kiel, Germany, June 28, 1912] suggest that the atomic nucleus can be modeled as a droplet of liquid (as previously proposed by George Gamow), an idea that works very well in determining properties of nuclei. *See also* 1929 PHY; 1939 PHY.

Arthur Dempster discovers uranium-235, the isotope that later will be important in developing the atomic bomb and nuclear power. *See also* 1945 TOOL.

Jesse Beams obtains the first separation of isotopes using a centrifuge. Centrifuging isotopes later becomes an important technique used in the production of uranium-235 for nuclear weapons. *See also* 1934 PHY; 1944 MATR.

Sir James Chadwick of England wins the Nobel Prize for physics for his discovery of the neutron. *See also* 1932 PHY.

I Tools

British scientists, led by Robert Watson-Watt, conduct experiments leading to the first radar. They detect faint signals from passing aircraft by placing a van loaded with short-wave receivers about 16 km (10 mi) from the powerful short-wave transmitting station at Daventry, England. By June they have a cathode-ray apparatus on which planes can be seen. By September they can measure the height of an aircraft flying 24 km (15 mi) away. *See also* 1932 ELEC; 1937 ELEC.

→ Transportation

In Oklahoma City, newspaper editor Carl Magee proposes

the use of parking meters. The first appear in town this year. H.C. North, a clergyman, gets the first ticket for not putting in his coin, but manages to talk his way out of the fine, claiming he had just gone to get change for the meter.

Buckminster Fuller introduces his three-wheeled Dymaxion automobile at the Chicago World's Fair, a streamlined car designed to maximize gain from minimum input of energy. *See also* 1934 TRAN.

1936

◀ Anthropology

Scottish-South African paleontologist Robert Broom [b. Paisley, Scotland, November 30, d. 1951] finds a fragmentary skull of an adult australopithecine at Sterkfontein Cave in South Africa. *See also* 1924 ANTH; 1938 ANTH.

★ Astronomy

The 500-cm (200-in.) telescope designed by George Ellery Hale is delivered to its site at Mt. Palomar in southern California in April and grinding and polishing operations on it are started, but World War II causes its final installation to be delayed. *See also* 1934 AST; 1948 AST.

❖ Biology

Russian biochemist Alexander Ivanovich Oparin [b. near Moscow, March 3, 1894, d. Uglich (Russia), April 21, 1980] addresses the origin of life in his book *The Origin of Life on Earth*. He puts forward the idea that life evolved in random chemical processes in the ocean, which became a biochemical soup conducive to early life forms, still the

most popular theory. *See also* 1953 BIO.

Tadeusz Reichstein isolates cortisone, independently of Edward C. Kendall, and finds its structure. *See also* 1935 BIO; 1950 MED.

Wendell Stanley isolates nucleic acids from the tobacco mosaic virus, which later will be found to cause the viral activity. *See also* 1935 BIO.

Andrei Nikolaevitch Belozer-sky isolates DNA in the pure state for the first time. *See also* 1929 CHEM.

Czechoslovakian-American biochemists Carl Ferdinand Cori [b. Prague, December 15, 1896, d. Cambridge, Massachusetts, October 20, 1984], Gerty Theresa Radnitz Cori [b. Prague, August 15, 1896, d. St. Louis, Missouri, October 26, 1957] isolate glucose-1-phosphate, which becomes known as the "Cori ester."

They find it is produced by phosphorylase, which both breaks down and synthesizes starches. This discovery helps explain the synthesis of glycogen and starch by enzyme action. *See also* 1947 BIO.

John Joseph Bittner [b. Meadville, Pennsylvania, February 25, 1904, d. Minneapolis, Minnesota, December 14, 1961] shows that a mouse mother's milk can sometimes transmit cancer, the first significant evidence since the work of Peyton Rous that some cancers might be caused by viruses. *See also* 1910 MED.

Sir Henry Dale of England and Otto Loewi of Austria win the Nobel Prize in physiology or medicine for their work on the chemical transmission of nerve impulses. *See also* 1914 BIO; 1921 BIO.

Chemistry

Peter Debye of the Netherlands wins the Nobel Prize in chemistry for his study of dipolar moments. *See also* 1916 PHY.

Communication

The British Broadcasting Corporation (BBC) starts regular public daily television broadcasts in Great Britain, the first regular electronic public television service anywhere (all earlier broadcasts used mechanical scanning). *See also* 1932 COMM.

The Agfacolor process of color photography is invented, based on color dyes first introduced by Siegrist and Fisher. *See also* 1912 COMM; 1939 COMM.

Computers

Konrad Zuse [b. Berlin, June 22, 1910, d. Hünfeld, Germany, December 18, 1995] builds a primitive form of digital computer using electromagnetic relays instead of tubes. In 1939 he succeeds in obtaining funding from the German government to develop his machine further. *See also* 1832 COMP; 1937 COMP.

Construction

Boulder Dam, later christened Hoover Dam, is completed on the Colorado River, creating Lake Mead, the world's largest reservoir. *See also* 1933 CONS.

Earth science

Inge Lehmann [b. Copenhagen, Denmark, May 13, 1888, d. February 21, 1993] proves the existence of the solid inner core of Earth (within the liquid outer core) by analyzing P waves that had traveled through the two layers of the core. *See also* 1906 EAR; 1939 EAR.

Electronics

Frans Michel Penning [b. 1894, d. 1953] invents a means for confining electrical currents within radio tubes. It later is modified for containing electrons and named the Penning trap. *See also* 1973 PHY.

Materials

Catalytic cracking is developed for refining petroleum. *See also* 1911 MATR.

A bridge completed at Aue, Germany, is the first to use prestressed concrete. *See also* 1903 CONS.

Mathematics

In August Alan Turing's paper "On Computable Numbers with an Application to the *Entscheidungsproblem*" describes the "Turing machine," an imaginary machine that can solve all problems that are computable. In fact, the definition of "computable" is that the problem can be solved by a Turing machine. This paper solves Hilbert's 23rd, the decidability problem or *Entscheidungsproblem*, by showing that it is not possible to devise a method for determining the truth or falsity of all statements that can be made in a part of formal logic called the predicate calculus. Therefore, there is no single way to prove or disprove all logical statements. Alonzo Church [b.

Washington, DC, June 14, 1903, d. Hudson, Ohio, August 11, 1995], independently of Turing, shows that there is no single method for determining whether or not a statement in mathematics is provable or even true (Church's theorem). *See also* 1900 MATH.

Medicine & health

Italian pharmacologist

Alan Mathison Turing

[b. London, June 23, 1912, d. Wilmslow, Cheshire, England, June 7, 1954]

Before World War II, Turing showed that an idealized machine (a universal Turing machine) using a few simple operations can calculate the values of all functions that a mathematician can compute. Despite this, Turing proved that some mathematical results remain beyond calculation. During the war Turing was instrumental in building a machine that decoded enemy messages, a prototype for electronic computers. After the war Turing developed such computers. Turing's 1952 study of the mathematics of fluid interactions helped biologists show how organisms develop and helped chemists analyze fluids with periodic properties.

based on a technique intended to cure mental illness with brain surgery. Prefrontal lobotomy had just been popularized in Europe by the Portuguese physician Egas Moniz. *See also* 1891 MED; 1949 MED.

Physics

Louis Néel [b. Lyon, France, November 22, 1904, d. Brive la Gaillarde, France, November 14, 2000] discovers antiferromagnetism. *See also* 1970 PHY.

Victor Franz Hess of Austria and Carl Anderson of the United States win the Nobel Prize for physics, Hess for his discovery of cosmic radiation and Anderson for his discovery of the positron. *See also* 1912 AST; 1932 PHY.

Tools

German-American physicist Erwin Wilhelm Mueller [b. Berlin, June 13, 1911, d. Washington, DC, May 17, 1977] develops the field-emission microscope, a device for observing a needle tip by using the electrons it emits as it is heated to make an image on a fluorescent screen. With improvements, it will become the first device to show individual atoms. *See also* 1981 TOOL.

Transportation

Ferdinand Porsche [b. Maffersdorf (Czech Republic), September 3, 1875, d. Stuttgart, Germany, January 30, 1951] introduces the Volkswagen (people's car), known as the "Beetle" because of its shape. It becomes the car with the largest production run in history, overtaking that of the Model T Ford at 15,000,033 units in 1972. *See also* 1908 TRAN.

German engineer Heinrich Focke [b. Bremen, Germany,

October 8, 1890, d. Bremen, February 25, 1979] develops the first practical helicopter, the Focke-Achgelis Fa-61, which successfully flies on June 26. By changing the angle of the rotor axis, the Fa-61 can fly forward or backward. *See also* 1907 TRAN.

Germany builds a secret facility for construction of experimental liquid-fueled rockets. *See also* 1934 TRAN; 1937 TRAN.

1937

► Anthropology

Franz Weidenreich [b. Edenkoben, Germany, June 7, 1873, d. New York City, July 11, 1948] discovers the first skull of Peking man. *See also* 1929 ANTH.

★ Astronomy

Grote Reber [b. Wheaton, Illinois, December 22, 1911, d. Tasmania, December 20, 2002] builds in his backyard the first intentional radio telescope, a 9.4-m (31-ft) diameter dish, which he begins to receive signals from space in 1938. *See also* 1931 TOOL; 1946 AST.

Dutch-American astronomer Peter Van de Kamp [b. Piet Van de Kamp, Kampen, Netherlands, December 26, 1901, d. 1995] initiates a 20-year search of 54 nearby stars in an attempt to find stars with planetary systems, but his claims of success (notably Barnard's star, identified as having a giant planet in 1963) are largely refuted by other astronomers. *See also* 1995 AST.

■ Biology

Hans Adolf Krebs discovers (but does not work out completely) the citric-acid cycle, usually called the Krebs cycle, which is the cycle of oxidation and energy production of all food in living cells. In the cycle, which involves changes in several compounds, carbon-carbon bonds in food molecules are broken. The carbon is expelled as carbon dioxide. The energy that held the carbon atoms together is released and stored in adenosine triphosphate (ATP). *See also* 1929 BIO; 1953 BIO.

William Rose establishes that only ten of the approximately twenty amino acids found in proteins are essential for rats. Later he will find that only eight of these are essential for humans. *See also* 1935 BIO.

English plant pathologist Frederick Charles Bawden [b. North Tawton, England, August 18, 1908, d. 1972] and coworkers discover that the tobacco mosaic virus contains ribonucleic acid (RNA). *See also* 1936 BIO; 1955 BIO.

Biochemist Conrad Arnold Elvehjem [b. McFarland, Wisconsin, May 27, 1901, d. Madison, Wisconsin, July 27, 1962] discovers nicotinic acid, or niacin, a B vitamin sometimes termed vitamin B₃. *See also* 1935 BIO; 1938 CHEM.

Albert Francis Blakeslee [b. Geneseo, New York, November 9, 1874, d. Northampton, Massachusetts, November 16, 1954] discovers that the alkaloid colchicine, derived from the autumn crocus, produces mutations in plants by allowing chromosomes to double without the cell dividing. *See also* 1926 BIO.

Albert Szent-Györgyi of Hungary wins the Nobel Prize in physiology or medicine for his study of vitamin C and respiration. *See also* 1930 CHEM.

William Astbury is the first to use X-ray diffraction to study a nucleic acid. *See also* 1934 BIO; 1953 BIO.

□ Chemistry

Sir Walter Haworth of England and Paul Karrer of Switzerland win the Nobel Prize in chemistry, Haworth for his work on carbohydrates and vitamin C and Karrer for his work on carotenoids, flavins, and vitamins. *See also* 1934 CHEM; 1931 BIO.

◀ Communication

American law student Chester Carlson [b. Seattle, Washington, February 8, 1906, d. New York, September 19, 1968] invents xerography, the first method of copying to be based on properties of selenium. His first efforts are extremely crude, however, and many years of development lie ahead before he has a commercial product. *See also* 1780 COMM; 1947 COMM.

Alec Harley Reeves [b. Redhill, Surrey, England, March 10, 1902, d. October 13, 1971] in England describes a transmission system in which analog sound is transformed into electrical pulses by a sampling process. The receiver transforms these pulses back into an analog sound signal. This is the basic method used in CD recordings. *See also* 1979 COMM.

■ Computers

John Vincent Atanasoff [b. Hamilton, New York, October 4, 1903, d. New Market, Maryland, June 15, 1955] conceives of the first electronic computer, a machine for solving systems of linear equations. *See also* 1936 COMP; 1939 COMP.

Mathematician Georges Stibitz [b. York, Pennsylvania, April 30, 1904, d. Hanover, New Hampshire, January 31, 1995], while working for Bell Telephone Laboratories, develops the first binary cir-

cuit, a combination of batteries, lights, and wires based on Boolean algebra that can add two binary numbers. He calls the device "model K" or "Kitchen adder" because he built it in his kitchen. This circuit becomes instrumental in the development of subsequent electromechanical computers at Bell Labs. *See also* 1936 COMP; 1938 COMP.

■ Earth science

A.V. Kazakov explains the origin and distribution of beds of phosphate rock as a result of ocean currents, with the rock being deposited where cold currents upwell. Such places encourage vast populations of living things whose remains and fecal pellets are the source of the phosphorus in the rock. *See also* 1820 FOOD.

■ Electronics

Brothers Russel H. [b. Washington, DC, April 24, 1898, d. July 28, 1959] and Sigurd Fergus Varian [b. Syracuse, New York, May 4, 1901, d. October 18, 1961] develop the klystron, a vacuum tube capable of generating microwaves that will be used in radar transmitters. *See also* 1921 ELEC; 1939 ELEC.

■ Food & agriculture

The Miracle Mixer, soon renamed the Waring Blender (with an "o") after bandleader Fred Waring — Frederick J. Ossius, inventor of the mixer, was the brother-in-law of Waring's publicity director — is introduced at the National Restaurant Show in Chicago, Illinois. The Blender is sold primarily to bars to make frozen daiquiris and not extensively promoted for home use until 1947.

Early digital computers

Except for a few analog computers used in special applications, all electronic computers today are digital. Digital computers were first experimented with during the late 1930s and early 1940s. They use binary numbers to represent numbers and characters and to perform calculations. Binary numbers consist of 0's and 1's and are therefore best suited to be handled by electronic circuits. For example, 0's can be represented by a negative current and 1's by a positive current.

George Stibitz, a mathematician at Bell Labs, was the first prominent experimenter to use binary numbers in a calculating device, although his device was electromechanical, and not electronic. In 1937 Stibitz built at his home a very simple adding device that could add two binary numbers. Subsequently, he built simple binary multipliers and dividers. Together with Sam Williams of Bell Labs he developed the complex calculator (also known as the Bell Telephone Lab Computer Model 1, or BTL Model 1). The calculator, completed at the end of 1939, contained 400 telephone relays. A teletype machine was used for data input and output. Two departments at Bell Labs that had to perform intensive calculations were connected to the BTL Model 1 via two remote teletype machines that functioned as computer terminals. In 1940 Stibitz linked the computer via telegraph lines to a terminal at Dartmouth College in New Hampshire, where mathematicians at a congress could enter calculations and receive a result a minute later.

Subsequently, Bell Labs developed several other calculators, of which the BLT Model V, completed in 1946, contained 9000 relays and weighed 10 tons. Its performance, considered very good at the time, was inferior to a present-day pocket calculator from a discount store: Multiplication of two seven-digit numbers took 1 second and their division 2.2 seconds.

In Germany, independently, Konrad Zuse, after having built a binary-number-based mechanical computer called Z_1 in his parents' sitting room, also used telephone relays in a computer called Z_2 . Both were built during the period 1936–39. A friend, Helmuth Schreyer, had proposed the use of vacuum tubes for switching elements, but because of the war conditions, vacuum tubes were difficult to obtain and Zuse used relays instead. The Z_3 , also based on electromechanical relays, was completed in 1941; it became the first universal computer that was controlled by a program. The Z_3 was unreliable, however, and in 1944 Zuse replaced it with the Z_4 . The first three Zuse computers were destroyed by bombing during World War II and the fourth was a casualty of the disorder at the end of the war.

Although many engineers at that time preferred electric relays because they were more reliable than vacuum tubes, it was the vacuum tube that emerged victoriously from the decade 1940–50, mainly because of the tremendous speed at which logic circuits equipped with vacuum tubes could perform calculations.

The theoretical physicist John V. Atanasoff and his assistant Clifford Berry had already completed a prototype of the vacuum-tube-based computer in 1942. In many aspects the Atanasoff-Berry computer (ABC) reflected the design of modern electronic computers. It was primarily developed to solve systems of linear equations, but fell victim to World War II, which called Atanasoff and Berry to other projects.

In England, during the war years, M.H.A. Newman, T.H. Flowers, and Alan Turing and coworkers also developed a series of vacuum-tube computers. The overall name for these computers of 1940–44 was Colossus. Colossus was used for deciphering German messages that had been encoded using Enigma machines.

❖ Materials

Dutch engineer Norman de Bruyne [b. Chile, November 8, 1904, d. March 7, 1997] develops the composite plastic Gordon-Aerolite, which consists of high-grade flax fiber bonded together with phenolic resin. Although the material is not a commercial success, it paves the way for fiberglass. *See also* 1942 MATR.

Σ Mathematics

Ivan Matveevich Vinogradov [b. Milolyub, Russia, September 14, 1891, d. Moscow,

March 20, 1983] proves that every sufficiently large even integer is the sum of four primes, the closest result to that time to Goldbach's conjecture that every even integer greater than two is the sum of two primes. *See also* 1742 MATH; 1955 MATH.

♥ Medicine & health

Italian pharmacologist Daniele Bovet, working at the Pasteur Institute in France, develops the first antihistamine. *See also* 1957 MED.

A virus disease in a woman in

the West Nile region of Uganda is found to be new to science, although related to several types of encephalitis. The disease, later christened West Nile virus, will spread throughout Africa and Eurasia, primarily in infected birds and through mosquitoes (humans, who become ill and sometimes die from the disease do not transmit it). *See also* 1999 MED.

Italian doctors Ugo Cerletti [b. Conegliano, Italy, September 12, 1877, d. July 27, 1963] and Lucio Bini [b. Rome, September 18, 1908, d. 1964]

develop the first form of electroconvulsive therapy (ECT), often known as "shock treatment," for treating schizophrenia. *See also* 1929 MED.

South African-American microbiologist Max Theiler [b. Pretoria, South Africa, January 30, 1899, d. New Haven, Connecticut, August 11, 1972] introduces a vaccine against yellow fever. *See also* 1951 MED.

⌘ Physics

Carl Anderson, Seth Neddermeyer, Edward Stevenson, and Jabez Curry Street [b. Opelika,

Alabama, May 5, 1906, d. November 7, 1989] discover what comes to be called the mu meson (now known as the muon) in cosmic radiation. It is a subatomic particle with mass in between that of the proton and electron (later measured at 207 times the mass of the electron). The muon is widely assumed — for most of the next ten years — to be the exchange particle predicted by Hideki Yukawa in 1935 (although its only resemblance to the Yukawa particle is a similar mass). The Yukawa particle (now called the pion) will be observed in 1947. *See also* 1935 PHY; 1947 PHY.

Russian physicists Igor Yevgenyevich Tamm [b. Vladivostok, Russia, July 8, 1895, d. Moscow, April 12, 1971] and Ilya M. Frank [b. St. Petersburg (Leningrad, Soviet Union), October 23, 1908, d. Russia, June 22, 1990] develop a theoretical explanation of Cherenkov radiation, the electromagnetic radiation caused when electrons accelerate. *See also* 1934 PHY; 1958 PHY.

Italian-American physicist Emilio Segrè [b. Tivoli, Italy, February 1, 1905, d. Lafayette, California, April 22, 1989] produces technetium (Tc), the first artificial element.

Russian physicist Peter Leonidovich Kapitza [b. Kronstadt, Russia, July 8, 1894, d. May 8, 1984] discovers superfluidity in helium 2. At 2.2 K (-456°F) helium becomes superfluid, having a viscosity about one thousandth that of the least viscous gas at room temperature. The term *superfluidity* will be coined by Peter Kapitza to describe this in 1941. *See also* 1930 PHY; 1938 PHY.

H. A. Kramers introduces the charge conjugation operation

in November and declares that particle interactions are invariant under it. In the charge conjugation operation, positive charges are replaced by negative ones and vice versa. *See also* 1957 PHY.

Isidor Rabi and Polykarp Kusch [b. Blankenburg, Germany, January 26, 1911, d. Dallas, Texas, March 20, 1993] develop the magnetic resonance method for studying the atomic nucleus. *See also* 1971 MED.

Clinton Davisson of the United States and George Paget Thomson of England win the Nobel Prize for physics for their discovery of electron diffraction by crystals. *See also* 1927 PHY.

→ Transportation

Frank Whittle and A.A. Griffith build the first working jet engine in England; the same year, Hans Pabst von Ohain [b. 1911, d. 1998] and Max Adolf Müller develop independently a similar engine. *See also* 1939 TRAN.

The first rocket tests are performed at the Baltic research station at Peenemünde. One of the leaders of the team is Wernher von Braun; Walter R. Dornberger [b. Germany, September 6, 1895, d. January 1, 1980] organizes the construction efforts that lead to the V-

2 rocket. *See also* 1936 TRAN; 1938 TRAN.

The Zeppelin Hindenburg burns in a hydrogen fire while trying to land in Lakehurst, New Jersey. The crash, which kills 36 of the 97 aboard, is captured on film, and a live radio broadcast of the disaster is recorded. The sight and sound is so horrifying that the crash effectively ends rigid airship development, although the United States continues to make nonrigid airships, called blimps, for coastal patrol. *See also* 1900 TRAN.

1938

◀ Anthropology

Robert Broom finds a complete hominid skull at Kromdraai Cave in South Africa. The skull is later recognized as the first known fossil of *Paranthropus* (a.k.a. *Australopithecus*) *robustus*. *See also* 1936 ANTH; 1946 ANTH.

★ Astronomy

Dutch-American astronomer Gerard Kuiper finds the relationship between spectral type and biometric correction for a star, making it possible to determine the luminosity of a star over all wavelengths.

Hans Bethe and, independently, Carl Friedrich von Weizsäcker propose a new theory of the cause of the energy

produced by stars — nuclear fusion of hydrogen into helium. Their basic concept, with minor modifications, continues to be accepted today. *See also* 1925 AST; 1952 TOOL.

American theoretical physicist J. Robert Oppenheimer [b. New York, New York, April 22, 1904, d. Princeton, New Jersey, February 18, 1967] and George Volkoff [b. Moscow, February 23, 1914, d. Vancouver, Canada, April 24, 2000] predict the existence of rapidly rotating neutron stars. These will be discovered in 1967 by Jocelyn Bell and named pulsars. *See also* 1967 AST.

Arthur Compton shows that cosmic rays begin as the nuclei of atoms, especially hydrogen nuclei (protons) from space that produce other types of particles when they collide with the atoms of the atmosphere. *See also* 1931 AST.

↗ Biology

Captain Hendrik Goosen catches a living coelacanth in the Indian Ocean off the African coast. The fish is recognized as unusual by Marjorie Courtney-Latimer, curator of a local natural-history museum, and identified by ichthyologist J.L.B. Smith. The species had been believed to have been extinct for 65,000,000 years.

Gerard Peter Kuiper

[b. Harenkarspel, Netherlands, December 7, 1905, d. Mexico City, December 25, 1973]

Although he contributed to astrophysics, established the atmosphere of Saturn's moon Titan, and discovered Saturn's moon Miranda and Neptune's Nereid, Kuiper's prediction of thousands of comets traveling near the orbit of Neptune, now called the Kuiper belt, has become his best-known achievement.



Britton Chance, American biophysicist [b. Wilkes-Barre, Pennsylvania, July 24, 1912], working with G. Brainerd, uses a mechanical computer to solve nonlinear equations that describe how an enzyme reacts with its substrate. His work with the enzyme peroxidase results in confirmation of the theory that enzymes work by binding briefly to their substrate (the material that the enzyme catalyzes). *See also* 1904 BIO; 1946 BIO.

Hans Spemann proposes taking the nucleus of a cell from an embryo or an adult and inserting it into an egg, allowing the development of an animal clone. *See also* 1952 BIO.

Corneille Heymans of Belgium wins the Nobel Prize in physiology or medicine for his discoveries in respiratory regulation. *See also* 1927 BIO.

Chemistry

Archer J.P. Martin [b. London, March 1, 1910, d. July 28, 2002] and Richard Laurence Millington Synge [b. Liverpool, England, October 28, 1914, d. August 1994] begin the work that leads to paper chromatography, using chromatography with a solvent in a column of silica to separate amino acids. Chromatography is analysis of chemicals from color bands that form because chemicals of different molecular weights travel through a medium (such as paper) at different speeds. *See also* 1930 CHEM; 1944 CHEM.

Swiss chemists Arthur Stoll and Albert Hofmann discover lysergic acid diethylamide (LSD). *See also* 1943 CHEM.

Austrian-German chemist Richard Kuhn [b. Vienna,

Austria, December 3, 1900, d. Heidelberg, Germany, July 31, 1967] isolates vitamin B₆ from skim milk and wins the Nobel Prize in chemistry for his carotenoid and vitamin research. *See also* 1937 BIO.

Communication

A Symbolic Analysis of Relay and Switching Circuits by Claude Elwood Shannon [b. Gaylord, Michigan, April 30, 1916, d. Medford, Massachusetts, February 24, 2001], his master's thesis, uses Boolean algebra to analyze relay circuits and switches and to determine their optimum arrangement. *See also* 1927 COMM; 1949 COMM.

Hungarian Lazlo Biró [b. 1900, d. 1985] patents the first ballpoint pen that is commercially successful. *See also* 1895 COMM.

Computers

German scientist Konrad Zuse completes the Z₁. It is the first working computer to use a binary code. *See also* 1937 COMP; 1940 COMP.

Earth science

British steam engineer Guy Stewart Callendar determines that human activities are causing an increase in the amount of carbon dioxide in Earth's atmosphere. *See also* 1967 ECOL.

Food & agriculture

Soviet biologist Trofim Denisovich Lysenko [b. Karlovka, Poltava Oblast (Ukraine), September 29, 1898, d. Kiev, Russia, November 20, 1976] is named president of the Soviet Academy of Agricultural Sciences. With Joseph Stalin as his chief supporter, Lysenko gains control of Soviet biological research,

imposing his incorrect view that acquired characteristics can be inherited.

Teijiro Yabuta and Yusuke Sumiki extract gibberellin A from a soil fungus and find that it is a potent growth hormone for rice. *See also* 1952 FOOD.

The Nestlé Corporation after eight years of development, produces the first satisfactory "instant" coffee, or dried coffee powder that can be reconstituted by adding hot water. *See also* 1903 FOOD.

Materials

Nylon, invented in 1934 by Wallace Carothers of DuPont, goes on sale in the United States in the form of toothbrush bristles. By 1939 it is available in limited amounts as yarn for stockings. *See also* 1935 MATR; 1940 MATR.

German chemist Paul Schlack [b. December 22, 1897, d. 1987] develops "perlon," a synthetic fiber. *See also* 1892 MATR; 1940 MATR.

DuPont chemist Roy Plunkett [b. New Carlisle, Ohio, June 26, 1910, d. May 12, 1994] on April 6 accidentally discovers the first form of Teflon in the residue of refrigeration gases.

Katherine Burr Blodgett [b. Schenectady, New York, January 10, 1898, d. Schenectady, October 12, 1979] discovers a method for covering glass with an extremely thin film that eliminates reflection of light. Applications include camera and binocular lenses and scientific instruments.

Mathematics

Kurt Gödel proves that if the commonly accepted axioms for set theory, known as the Zermelo-Fraenkel axioms, are

consistent with each other, they will continue to be consistent if the controversial axiom of choice is added to them. The axiom of choice allows the mathematician to specify one element from each subset of an infinite number of subsets (such as always picking the left shoe out of an infinite set of pairs of shoes). *See also* 1904 MATH.

Medicine & health

The Behavior of Organisms by Burrhus Frederick Skinner [b. Susquehanna, Pennsylvania, March 20, 1904, d. Cambridge, Massachusetts, August 18, 1990] is published. The behaviorist school of psychology espoused by Skinner, which emphasizes conditioning responses with reinforcement as the main form of learning, becomes dominant in the United States for several decades.

English surgeon Philip Wiles [b. 1899, d. 1967] develops the first total artificial hip replacement, using stainless steel. *See also* 1905 MED.

Physics

German physicist Otto Hahn, working with Lise Meitner and Fritz Strassman [b. Boppard, Germany, February 22, 1902, d. Mainz, West Germany, April 22, 1980], is the first to split the atom of uranium, opening up the possibility of a chain reaction and atomic bombs. In March 1938, Meitner flees Hitler-controlled Germany for Sweden, taking the problem of uranium atom-splitting with her. In Sweden she determines that she and Hahn had indeed been splitting uranium. *See also* 1939 PHY.

Fritz London [b. Breslau (Wrocław, Poland) 1900, d. 1954] proposes that superflu-

idity in helium is caused by the bosonic condensation of helium atoms; that is, the cold atoms behave as bosons and act together as a single entity. *See also* 1937 PHY; 1941 PHY.

Ernst C.G. Stückelberg formulates the law of baryon conservation; that is, the number of heavy particles (baryons), such as protons and neutrons, stays the same in any closed system. The purpose is to account for the apparent stability of the proton, which otherwise cannot be explained.

Paul Dirac attempts to link the Hubble constant, which describes the age and size of the universe, to physical constants that describe subatomic particles.

Sir Nevill Francis Mott [b. Leeds, England, September 30, 1905, d. Milton Keynes, England, August 8, 1996] and Ronald W. Gurney formulate a theory explaining image formation in photographic emulsions.

Enrico Fermi of Italy wins the Nobel Prize for physics for his work with thermal neutrons. *See also* 1934 PHY.

I Tools

Manfred von Ardenne [b. Hamburg, Germany, January 20, 1907, d. Dresden, Germany, May 26, 1997] gives a

demonstration of the scanning electron microscope. *See also* 1936 TOOL.

The radio altimeter is introduced; it reports a plane's altitude on the basis of radio signals from a known source. *See also* 1904 TOOL.

U.S. engineer Thomas Ross develops the first machine that can learn from experience. It is a mechanical mouse that runs on toy-train tracks and learns by trial and error to find its way through mazes. *See also* 1948 TOOL.

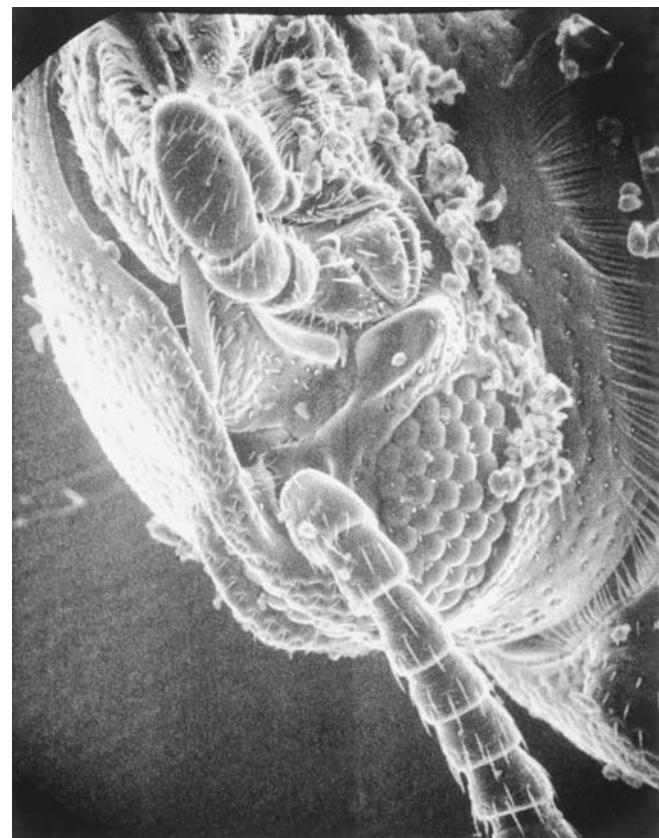
→ Transportation

Germany's liquid-fueled rocket experiments, under the direction of Wernher von Braun, succeed in producing a rocket that can travel 18 km (11 mi). *See also* 1934 TRAN; 1942 TRAN.

1939

★ Astronomy

By comparing photographs taken in 1909, 1921, and 1938, John Charles Duncan at Mt. Wilson Observatory discovers that the Crab Nebula expands. Calculating the initial explosion from the rate of expansion establishes that the nebula is some 800 years old. *See also* 1054 AST; 1948 AST.



FLOUR BEETLE IMAGED WITH SCANNING ELECTRON MICROSCOPE The magnification is only 700 times, which is not high by ordinary electron microscope standards, but the ability to show surface detail is what makes images from this form of microscope so dramatic and so useful. The subjects appear almost three-dimensional because of the depth of focus. The scanning electron microscope was re-invented by Vladimir Zworykin in the United States in 1942 and greatly improved by D. McMullan in 1951 before it came into general use.

J. Robert Oppenheimer and George Michael Volkoff [b. Moscow, February 23, 1914, d.

April 2000] calculate that if the mass of a neutron star is more than 3.2 times the mass of the Sun, the entire mass of the star will collapse to a point, creating what will come to be known as a black hole. This is before the discovery of the first neutron star, however. *See also* 1917 AST; 1967 AST.

↗ Biology

Andrei Belozersky starts his experimental work showing that both DNA and RNA are always present in bacteria.



Lise Meitner

[b. Vienna, Austria, November 7, 1878, d. Cambridge, England, October 27, 1968]

Meitner collaborated with Otto Hahn in Germany from 1906 through 1938. Together they found the first long-lived isotope of protactinium, establishing it as a new element. They also produced uranium fission, but Hahn failed to recognize that uranium atoms were splitting. In 1938 Meitner, in exile from Germany because of her Jewish heritage, worked out the correct explanation in collaboration with her similarly exiled nephew Otto Frisch, who named the process nuclear fission.

Edward Adelbert Doisy [b. Hume, Illinois, November 13, 1893, d. St. Louis, Missouri, October 23, 1986] isolates vitamin K. *See also* 1935 BIO; 1943 BIO.

Chemistry

Chemist Marguerite Perey [b. Villemomble, France, 1909, d. Louveciennes, France, 1975] discovers the chemical element francium (Fr).

Linus Pauling's *The Nature of the Chemical Bond and Structure of Molecules and Crystals*, subtitled *An Introduction to Modern Structural Chemistry*, becomes a classic work of chemistry, still used today. In *The Nature of the Chemical Bond*, as it is usually called, Pauling details the relationships between chemical resonance and the three types of bonds that hold atoms together in compounds and in molecules. He also calculates bond strengths and how interatomic distances affect the structure of molecules and crystals. *See also* 1933 CHEM.

Baron Alexander Robertus Todd [b. Glasgow, Scotland, October 2, 1907, d. Cambridge, England, January 10, 1997] begins the analysis of the nucleotides that are the bases involved in building RNA and DNA, later found to be the "letters" of the genetic code. *See also* 1957 CHEM.

Adolf Butenandt of Germany and Leopold Ružička of Switzerland share the Nobel Prize in chemistry. Butenandt for his study of sexual hormones and Ružička for his work with atomic ring structures and terpenes. *See also* 1934 CHEM; 1935 CHEM.

Communication

The first commercial system of color photography in which a negative is produced first appears and is a success with skilled amateur photographers and cinematographers. *See also* 1936 COMM.

Vladimir Zworykin, Harley Iams, and George Morton develop the image iconoscope. The television camera tube has a semitransparent photocathode on which the image to be televised is projected. Electrons are emitted from this photocathode, forming an "electronic" image that subsequently is amplified, resulting in a higher sensitivity. Albert Rose [b. March 30, 1920, d. July 26, 1990] and Harley Iams develop at RCA Laboratories the orthicon, a television camera tube in which the plate on which the image is projected is scanned by an electron beam that resupplies electrons that have been emitted by photoemission. *See also* 1946 COMM.

Computers

George Stibitz and Samuel B. Williams build the Complex Number Computer (also called the Bell Telephone Lab Computer Model 1, or BTL Model 1), consisting of more than 400 relays, and connect it to three telex units, thus introducing the principle of operating a computer via a terminal. *See also* 1937 COMP; 1940 COMP.

Physicist John Atanasoff receives a grant of \$650 from Iowa State College to build the computer he had been thinking about since 1937. He hires electrical engineering student Clifford Berry [b. Gladbrook, Iowa, April 19, 1918, d. New

York, October 30, 1963] to work with him to build an electronic computer (or calculator) designed for finding the solutions to systems of linear equations. *See also* 1937 COMP; 1942 COMP.

Earth science

Walter Maurice Elsasser [b. Mannheim, Germany, March 20, 1904, d. October 14, 1991] suggests that the liquid iron core of Earth contains eddy currents that set up Earth's magnetic field. *See also* 1936 EAR.

Edward Victor Appleton confirms that radio waves are reflected by ionized particles caused as meteors pass through upper atmospheric layers and uses this phenomenon to measure the height of the E layer (sometimes called the Appleton layer) of the ionosphere, which is about 50 km (30 mi). The E layer is also the lower layer that reflects AM radio waves back to Earth, allowing radio transmission beyond the horizon. *See also* 1932 AST; 1947 AST.

Hannes Olof Gosta Alfvén [b. Norrköping, Sweden, May 30, 1908, d. April 2, 1995] publishes his theory that correctly relates auroras to magnetic storms — that is, rapid changes in part of Earth's magnetic field. *See also* 1950 EAR.

Electronics

John Turton Randall [b. Lancashire, England, March 23, 1905, d. Edinburgh, Scotland, 1984] and Henry Albert Boot [b. Birmingham, England, July 29, 1914, d. 1983] develop the first practical magnetron, a vacuum tube that produces radio waves of greater power

and higher frequency than possible with other means. Their work is based on various other forms of magnetron developed in the 1920s and 1930s. Secretly brought to the United States, the Randall-Boot magnetron becomes the central component of radar systems. *See also* 1937 ELEC; 1943 TOOL.

Food & agriculture

Paul Müller [b. Olten, Switzerland, January 12, 1899, d. Basel, Switzerland, October 13, 1965] discovers that DDT is a potent insecticide. *See also* 1874 FOOD; 1972 ECOL.

Materials

Powder metallurgy, the working of metals (and some carbides) by pressure and sintering, is introduced. *See also* 1925 MATR.

Mathematics

The first volume of mathematics attributed to Nicolas Bourbaki is published. This is the beginning of a project that attempts to synthesize all known mathematics. After this, it will continue to appear in numerous volumes, written by a group of mostly French mathematicians who use Bourbaki as a joint nom de plume.

Medicine & health

René Jules Dubos [b. Saint-Brice, France, February 2, 1901, d. February 20, 1982] searches for and finds two compounds produced by a soil bacterium that kill other bacteria. Today such compounds are called antibiotics. These are the first antibiotics to have been deliberately sought for this property. *See also* 1877 MED; 1944 MED.

The mathematics of Nicolas Bourbaki

In 1939 the first volume of *Elements de mathématique* ("elements of mathematics" — without the s to suggest that all mathematic(s) is a unit) by Nicolas Bourbaki appeared. This influential work, which eventually ran to 40 volumes, sought to recast all of mathematics into a consistent whole with the same symbolism used throughout. The author was identified in a 1949 biographical note as having been formerly with the Royal Poldavian Academy. Somewhat later he moved to the Mathematics Institute of the University of Nancago.

If these institutions seem a bit unfamiliar, do not be surprised. Like the redoubtable N. Bourbaki, they do not exist. Instead, Bourbaki is a pseudonym used by a group of mainly French mathematicians, including Jean Dieudonné, Henri Cartan, André Weil, and Samuel Eilenberg, with some other mathematicians loosely affiliated. The group formed itself in 1935, starting with graduates of l'Ecole Normale Supérieure. A fictitious Général Claude Bourbaki had been associated with the school since 1880, with his name adopted from a real 19th-century French general Bourbaki.

The aim of Nicolas Bourbaki was to lay out all of mathematics according to the ideas of the Formalists, who had been led by the German David Hilbert. Bourbaki introduced its own vocabulary and symbolism, which were influential worldwide during the 1960s and 1970s, but now are viewed as too complex (although some of the vocabulary and symbols continue in use).

Each volume is written by a committee and critiqued at a *congrès* featuring fine wine and gourmet food, paid for by Bourbaki's royalties. The group has kept young by limiting the age of its members to 50. In addition to the books, Bourbaki continues to sponsor frequent seminars.

Although the true identity of Nicolas Bourbaki has been known to mathematicians for many years, the members of the group have continued to pretend. When the mathematician Ralph P. Boas wrote an article about the group in a popular publication, the editors received a letter from Nicolas Bourbaki himself, protesting the article and claiming that there is no real Ralph P. Boas, but only a group of mathematicians claiming to be Boas.

On June 28 Harold A. Campbell, working with Karl Paul Link, isolates coumadin, which will become used as a blood thinner to prevent clots in several different medical conditions, such as irregular heartbeats. *See also* 1933 MED; 1944 FOOD.

Gerhard Domagk of Germany wins the Nobel Prize for physiology or medicine for discovery of the first sulfa drug, Prontosil. *See also* 1932 MED.

✿ Physics

In January Otto Hahn publishes the results of his experiments with uranium, but he is too cautious to call it nuclear fission. Also in January, Lise Meitner and Austrian-British physicist Otto Robert Frisch [b. Vienna, October 1, 1904, d. Cambridge, England, September 22, 1979] advance the theory that uranium when bombarded by neutrons breaks into smaller atoms. The term *fission* is their word for this

process. Physicists all over Europe and the Americas immediately repeat and extend the experiments. *See also* 1938 PHY.

John Ray Dunning [b. Shelby, Nebraska, September 24, 1907, d. August 25, 1975] is the first to confirm Lise Meitner's theory of uranium fission experimentally. Hungarian-American physicist Leo Szilard [b. Budapest, February 11, 1897, d. La Jolla, California, May 30, 1964] and Walter Henry Zinn [b. Kitchner, Ontario, December 10, 1906] confirm that fission reactions can be self-sustaining because of chain reactions. French scientists Frédéric and Irène Joliot-Curie also demonstrate that the fission of the uranium atom can lead to a chain reaction. *See also* 1942 ENER.

Biophysicist Richard Brooke Roberts [b. Titusville, Pennsylvania, December 7, 1910, d. April 4, 1980] discovers that a

fissioning uranium atom does not release all its neutrons at the same time. The "delayed neutrons" are an important element in controlling nuclear reactors. *See also* 1942 ENER.

Philip Hauge Abelson [b. Tacoma, Washington, April 27, 1913] identifies the products of uranium fission: three radioactive isotopes of antimony, six of tellurium, and four of iodine.

Homi Bhabha [b. Bombay, India, October 30, 1909, d. Mont Blanc, France, January 24, 1966] suggests the name *meson* for the middle-weight exchange particle predicted by Hideki Yukawa. *See also* 1935 PHY.

Niels Bohr proposes the liquid-drop model of the atomic nucleus independently of Hans Bethe and Carl von Weizsäcker, who had suggested the idea in 1935. Bohr uses the idea to explain atomic fission. *See also* 1935 PHY; 1949 PHY.

I Tools

Einstein writes the letter to President Roosevelt, dated August 2, that will lead to the U.S. effort to develop an atomic (fission) bomb.

Ernest Lawrence of the United States wins the Nobel Prize for physics for his invention of the cyclotron. *See also* 1931 TOOL

↗ Transportation

Igor Sikorsky constructs the first helicopter designed for mass production. It flies for the first time on September 14. *See also* 1923 TRAN; 1944 TRAN.

German engineer Hans Pabst von Ohain's jet engine becomes the first such engine actually to fly an airplane, the Heinkel He-178. The experimental plane reaches 500 km/hr (360 mph). *See also* 1937 TRAN.

1940

► Anthropology

In September four young men discover cave paintings, 17,000 years old, in Lascaux Cave in France. *See also* 1879 ANTH; 1991 ANTH.

▷ Chemistry

Philip Abelson and Edwin Mattison McMillan [b. Redondo Beach, California, September 18, 1907, d. El Cerrito, California, September 7, 1991] create the first element with an atomic number higher than that of uranium. Element number 93 is christened neptunium (Np) after the order of the planets — Neptune is beyond Uranus. *See also* 1941 CHEM.

Martin David Kamen, Canadian-American biochemist [b. Toronto, Ontario, August 27, 1913, d. Montecito, California, August 31, 2002], discovers carbon-14, the long-lived radioactive isotope of carbon that is among the most useful of all the radioactive isotopes, with a special use in dating ancient sites. *See also* 1945 BIO.

◄ Communication

The first U.S. color television broadcast takes place using a system developed by Peter Carl Goldmark [b. Budapest, Hungary, December 2, 1906, d. Port Chester, New York, December 7, 1977] for the Columbia Broadcasting System (CBS). *See also* 1953 COMM.

About this time Les Paul creates a better electronic guitar, known as "The Log," which has a solid body to minimize vibrations. This type comes to be preferred by many musicians to an ordinary acoustic guitar with an electric amplifier. *See also* 1931 COMM.

▀ Computers

Bletchley Park in England becomes a concentration of intellect to face the challenge of the German encoding machine Enigma. Among the scientists working at the center are Alan Turing, C.E. Wynn-Williams, and electrical engineer Thomas Harold Flowers [b. 1905, d. 1998]. They are developing a series of computers dedicated to decoding messages from the German forces. *See also* 1919 ELEC; 1943 COMP.

George Stibitz and Samuel B. Williams demonstrate the remote operation of a computer in New York from Dartmouth College, using a telex linked to a Bell Telephone Lab Computer Model 1, also called *Complex Calculator*. *See also* 1939 COMP; 1975 COMP.

Konrad Zuse completes the Z_2 . The device is a binary-coded computer similar in design to the Z_1 , but using telephone relays instead of mechanical logical circuits. *See also* 1936 COMP; 1941 COMP.

▀ Construction

The collapse of the four-month-old Tacoma Narrows bridge in Washington leads engineers to consider aerodynamic stability in bridges and buildings for the first time.

▀ Food & agriculture

Chemists working for Imperial Chemical Industries in the United Kingdom discover that plant hormones can be used as selective herbicides. This eventually leads W.G. Templeman and W.A. Sexton to develop the herbicidal synthetic hormone trademarked Methoxone (a sodium salt of 4-chlor-2-methyl-phenoxyacetic acid). *See also* 1896 FOOD; 1945 food

freeze-drying, developed earlier for medicines, is used for food preservation for the first time in the United States. *See also* 1906 FOOD.

◊ Materials

In Britain, John Rex Whinfield [b. Sutton, England, February 16, 1901, d. Dorking, England, 1966] and James Tennant Dickson invent the artificial fiber terylene, better known in the United States as dacron. The fiber is more resistant to heat than nylon and more resistant to wear than rayon (although not so wear-proof as nylon) and holds color better than either. *See also* 1935 MATR.

Σ Mathematics

Kurt Gödel shows that Georg Cantor's continuum hypothesis (that there is no infinite set of a size that fits between the sizes of the sets of natural numbers and real numbers) is consistent with the axioms of set theory. *See also* 1877 MATH; 1963 MATH.

♥ Medicine & health

Howard Florey [b. Adelaide, Australia, September 24, 1898, d. Oxford, England, February 21, 1968] and Ernst Boris Chain [b. Berlin, June 19, 1906, d. Ireland, August 12, 1979] at Oxford University obtain penicillin in a purified form and show that it can be used as a weapon against bacteria. *See also* 1928 MED; 1945 MED.

Karl Landsteiner and Alexander S. Wiener [b. Brooklyn, New York, March 16, 1907, d. November 6, 1976] discover a relationship between human blood cells and those of rhesus monkeys that leads them to discover the rhesus factor, more commonly called the Rh

factor. This factor, which can be positive or negative, affects the survival of newborns in certain instances. *See also* 1900 MED.

Herbert Evans uses radioactive iodine as a tracer to prove that iodine is used by the thyroid gland. *See also* 1896 BIO; 1944 BIO.

Dickinson W. Richards [b. Orange, New Jersey, October 30, 1895, d. Lakeville, Connecticut, February 23, 1973] and French-American physiologist André F. Cournaud [b. Paris, September 4, 1895, d. Great Barrington, Massachusetts, February 19, 1988] develop techniques to insert catheters into the hearts of patients. Over the next few years they will employ the technique to study stress, heart function and disease, and the effects of drugs on the heart. *See also* 1929 MED; 1956 MED.

Biochemist Vincent Du Vigneaud [b. Chicago, Illinois, May 18, 1901, d. White Plains, New York, December 11, 1978] identifies biotin, the compound previously known as vitamin H.

⊗ Physics

Maurice Goldhaber discovers that beryllium slows down fast neutrons and therefore makes them more likely to fission uranium. *See also* 1939 PHY; 1942 ENER.

I Tools

Donald William Kerst [b. Galena, Illinois, November 1, 1911, d. August 19, 1993] builds the first usable betatron, a type of particle accelerator that uses a rapidly pulsed magnetic field to accelerate electrons. *See also* 1931 TOOL; 1943 TOOL.

Creating elements

The ancient Greeks developed theories based on four “elements” — earth, air, fire, and water — although these were not thought of as elements in the modern sense of the word. The Greek elements were more like qualities. Salt tended toward earth with a little bit of water and fire in it, for example.

The modern conception of element was first proposed by 17th-century chemist Robert Boyle, who said that an element is a chemical that cannot be broken down into another substance. At that time, however, it was hardly clear which substances are elements and which are not. Several substances then known actually are elements according to this definition, specifically carbon, copper, gold, iron, lead, mercury, silver, sulfur, tin, and zinc. Other substances, such as water and potash, or even mixtures, such as air, were mistakenly believed to be elements because no one knew how to break them down.

Also, at that time not all the naturally occurring elements were known. Boyle just missed being the first person to discover a new element according to his definition, but he was anticipated by Henning Brand, who discovered phosphorus some five to ten years before Boyle's independent discovery.

In the 18th century many new naturally occurring elements were discovered and recognized as such. These include barium, beryllium, chlorine, chromium, cobalt, hydrogen, magnesium, manganese, molybdenum, nickel, nitrogen, oxygen, tellurium, titanium, tungsten, and zirconium. Even more were discovered in the first part of the 19th century, so when Dmitri Mendeléev set about developing the periodic table in 1869, he had 63 of the 90 naturally occurring elements to work with. (It is often thought that 92 elements occur naturally, but two of the elements below uranium — number 92 — in the periodic table are not found in nature.) Mendeléev's periodic table not only made some sense out of the growing number of elements, it also indicated what the properties of as yet undiscovered elements might be. When new elements were isolated, it was found that they fit right into the blanks in Mendeléev's table, occasionally with a minor adjustment in the scheme.

In 1914 Henry Moseley discovered why Mendeléev's periodic table worked, and improved on it. Moseley found that the differences in elements arise from the different number of protons in each atom of the element — although Moseley would not have put it quite that way. He was looking at the number of electrons, which is the same as the number of protons for un-ionized atoms. With Moseley's work it could be seen that there were just seven “holes” left in the periodic table (below uranium). Five of these were filled by the discovery of francium, hafnium, promethium, protactinium, and rhenium, all of which are found on Earth, although most are quite rare.

But that was not the whole story. Even before all of these elements were found, the first “new” element, technetium, was created in 1937. Emilio Segrè thought that since the element with atomic number 43 had not been discovered, it might be created. He got

some molybdenum (atomic number 42) that had been bombarded with deuterons (particles consisting of a proton bound to a neutron) from Ernest Lawrence. Careful chemistry revealed the traces of technetium in the sample. Some of the deuterons had stuck to the molybdenum nucleus, providing the extra proton that lifted the atom to element 43. In 1940 Segrè helped complete the list of 92 elements as part of the team that produced element 85, astatine. Neither of these occur naturally on Earth, although technetium has been recognized in some stars.

Around the same time as astatine was first produced, scientists found that they could go beyond the known 92 elements in the periodic table. Edwin McMillan was exposing uranium to accelerated neutrons in 1940. Some of the neutrons stuck to the uranium nucleus and then underwent beta decay (changing from neutron to proton by emitting an electron). On June 8, 1940, McMillan and Philip Abelson announced the discovery of element 93, which they named neptunium (because Neptune is the planet beyond Uranus). Later that year they showed that the same process also produced element 94, plutonium, exhausting the supply of planets beyond Uranus as names. Elements discovered later would be named for places and persons.

McMillan moved on to other things — radar and nuclear weapons; World War II had started. After the war, a team headed by Glenn T. Seaborg resumed the work of creating new elements. With amazing regularity the team announced one new element after another: americium, curium, berkelium, californium, einsteinium, and fermium — elements 95 to 100. All of these were created by adding protons to the nuclei of previously existing elements.

Subsequently, various groups extended the list to 109. When elements 108 (hassium) and 109 (meitnerium) were created in 1984 and 1982 (109 was made first), only a tiny number of atoms of each were produced. The new elements were recognized by their decay patterns, since all of the elements above uranium are radioactive. Many are so unstable that they last only a few seconds after creation. Hassium's first few atoms only lasted two-thousandths of a second. Scientists from the Society for Heavy Ion Research in Darmstadt, Germany, created elements 110 and 111 in 1994 and element 112 in 1996. Both Russian and American teams independently created element 114 in 1998 and the Russians added element 116 in 2000. There are good physical reasons why elements with odd atomic numbers are harder to create than those with even numbers, which is why elements 113 and 115 have been skipped. (Why new elements are nearly always created in even-numbered years, however, is a mystery.) None of the elements above 109 had an official name until 2003, when element 110 was named darmstadtium (Ds) after the place it was first produced, Darmstadt, Germany.

There is hope for stable elements above 116. Nuclear theory predicts that element 118 will be much more stable than 116, for example. As of 2003, however, the only element 118 “created” turned out to be a fraud. In the meantime, only one of the elements above uranium has won a secure place in society. Plutonium is a terrific element for making nuclear weapons.

✈ Transportation

At noon on October 1 the Pennsylvania Turnpike, the first modern highway in the United States, opens; local feed-and-tallow dealer Homer D. Romberger takes the first ticket. By October 6 the highway has its first traffic jam. *See also* 1925 TRAN.

In Los Angeles California the Arroyo Seco Parkway, destined to become the first part of the Los Angeles freeway system, opens. *See also* 1925 TRAN.

1941

★ Astronomy

Physicist Bengt Edlén [b. Gusum, Sweden, November 2, 1906, d. 1993] shows that the “coronium” lines in the solar corona are caused by strongly ionized iron, calcium, and nickel lines. (Astronomers had suspected an element unknown on Earth by analogy with helium discovered in the solar spectrum. They called the suspected element *coronium*.) From the degree of ionization the temperature of the corona is shown to be 1,000,000°C (1,800,000°F).

Ⓑ Biology

George Wells Beadle [b. Wahoo, Nebraska, October 22, 1903, d. Pomona, California, June 9, 1989] and Edward Lawrie Tatum [b. Boulder, Colorado, December 14, 1909, d. New York City, November 5, 1975] demonstrate that genes control chemical reactions in cells. Their theory becomes known as the “one-gene, one-enzyme hypothesis.” *See also* 1958 BIO.



Glenn Theodore Seaborg

[b. Ishpeming, Michigan, April 19, 1912, d. Lafayette, California, February 25, 1999]

In 1940 Seaborg started working with elements with higher atomic numbers than uranium’s 92 (transuranic elements). That year he was the second to produce an isotope of neptunium (93) and the first to produce plutonium (94). In 1944 his team added americium (95) and curium (96), followed in 1949 by californium (97) and berkelium (98). Seaborg recognized that thorium, uranium, and transuranic elements through element 103 form the actinides, a series of elements with very similar properties.

Ⓓ Chemistry

Glenn Seaborg and Edwin McMillan create element 94, plutonium (Pu), named for Pluto, the next planet beyond Neptune. *See also* 1940 CHEM; 1951 CHEM.

Arnold Beckman invents a spectrophotometer that measures the chemical composition of a sample based on the wavelengths of light reflected by the sample.

⌚ Communication

The first television broadcast license for a system using 525 scanning lines is issued by the FCC in the United States. The same year the FCC grants broadcasters permission to use commercials for financing programs. The National Broadcasting Company (NBC) and the Columbia Broadcasting System (CBS) start transmitting programs and commercials in New York City. *See also* 1936 COMM; 1948 COMM.

On October 10 the Radio Club of Columbia University, under the direction of FM’s inventor Edwin Armstrong, opens the first regularly scheduled FM station, WKCR. The opening words are “Good morning, hepsters, jitterbugs,

and other lovers of culture.” *See also* 1933 COMM.

💻 Computers

Konrad Zuse’s Z_3 computer, containing 2600 relays, is the first to use electromagnetic relays and a punched tape for data entry. It also makes use of an error-detecting code. The Z_3 is the first working universal computer controlled by a program. *See also* 1940 COMP; 1942 COMP.

⚡ Energy

Beauchamp E. Smith, Palmer Coslett Putnam, and coworkers in a series of experiments between 1937 and 1946 find that their windmill on Grandpa’s Knob near Rutland, Vermont, with two blades and a tip-to-tip diameter of 53.3 m (175 ft), erected this year, is the most efficient. It delivers 1250 kw of electricity to the grid until it loses a blade in 1945 and is shut down. *See also* 1931 ENER.

◊ Materials

Norton and Loring use X-ray diffraction methods to show that the relation between stress and extension known as Hooke’s law is caused by openings in the crystal structure of a solid, just as Hooke

wrote in 1679. *See also* 1679 TOOL.

Americans Lyle David Goodhue and W.N. Sullivan of the Department of Agriculture introduce the first aerosol containers. The containers produce vapors containing insecticides and are soon christened “bug bombs.”

The German I.G. Farbenindustrie begins to produce polyurethanes, plastics first developed between 1937 and 1939 by Otto Bayer. *See also* 1937 MATR.

♥ Medicine & health

Canadian-American surgeon Charles Brenton Huggins [b. Halifax, Nova Scotia, September 22, 1901, d. Chicago, Illinois, January 12, 1997] shows that administration of female sex hormones can be used to help control prostate cancer. *See also* 1903 MED; 1966 MED.

Russian-American microbiologist Selman Abraham Waksman [b. Priluki, Russia, July 22, 1888, d. Hyannis, Massachusetts, August 16, 1973] coins the term *antibiotic* to describe substances that kill bacteria without injuring other forms of life. *See also* 1940 MED; 1943 MED.

* Physics

Soviet physicist Georgii Niko-laevich Flerov [b. March 2, 1913, d. November 19, 1990] discovers spontaneous fission of uranium; that is, no bombardment with neutrons is needed. He soon will recognize that references to uranium fission have disappeared from scientific journals, alerting him to the likelihood that scientists in other countries are working on fission-based weapons. He then will urge the Soviet government to institute such a program, which is begun shortly thereafter. *See also* 1939 PHY; 1951 TOOL.

I Tools

On the day before the Pearl Harbor attack by the Japanese that plunges the United States into World War II, President Franklin D. Roosevelt signs the order that leads to the American and British development of the atomic bomb (nuclear-fission bomb). *See also* 1945 TOOL.

✈ Transportation

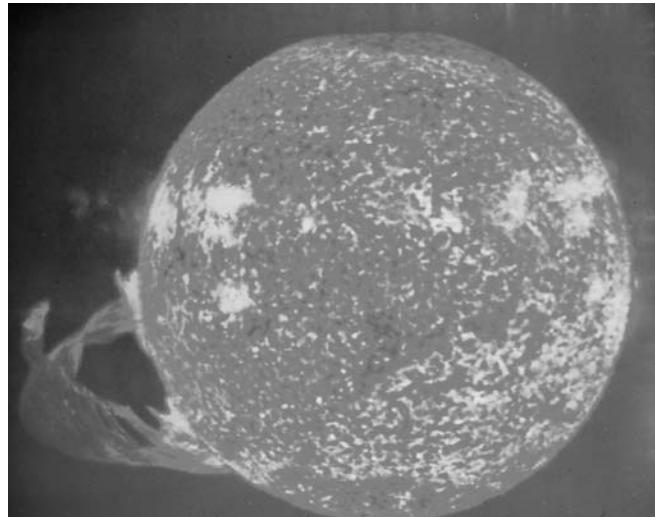
Honeywell installs the first electronic automatic pilot in several thousand bombers. *See also* 1932 TRAN; 1947 TRAN.

In May the *Gloster E28/39* or *Meteor* is the first British airplane powered by a jet engine, an outgrowth of the engine design first patented by Frank Whittle in 1930. *See also* 1937 TRAN; 1944 TRAN.

1942

* Astronomy

Static detected by British army physicist (James) Stanley Hey [b. Lake District, England, May 3, 1909] and his col-



MASSIVE SOLAR FLARE On September 1, 1859, Richard Christopher Carrington became the first to observe very bright spots on the Sun, which we now know are the giant storms called solar flares. George Ellery Hale determined in 1892 that solar flares are caused by outbursts of magnetism from the Sun. After Stanley Hey recognized in 1942 that solar flares can be detected at radio frequencies, scientists began monitoring the flares more closely. Large flares, like this one, can disrupt Earth's magnetic field.

leagues on February 27-28 is identified as coming from a solar flare — the first recognition that flares emit radio waves. The static had previously been attributed to intentional jamming by the Germans. *See also* 1946 AST.

Grote Reber makes the first radio maps of the universe, locating individual radio sources, including the radio galaxy Cygnus A, about

700,000,000 light-years away. *See also* 1946 AST.

Biology

Salvador Luria, Italian-American microbiologist, obtains the first good electron photomicrographs of a bacteriophage. *See also* 1916 BIO; 1945 BIO.

Ulf von Euler discovers the neurotransmitter piperidine. *See also* 1935 BIO; 1946 BIO.

Konrad Emil Bloch [b. Neisse, Germany, January 21, 1912, d. Burlington, Massachusetts, October 15, 2000] and David Rittenberg discovered that the two-carbon compound acetic acid is the major building block in the 30 or more steps in the body's formation of cholesterol, a waxlike alcohol found in all animal cells. *See also* 1964 BIO.

□ Chemistry

American chemist Louis Fieser [b. Columbus, Ohio, 1899, d. 1977] develops napalm, jellied gasoline that can be used as an incendiary weapon.

💻 Computers

John Atanasoff and Clifford Berry complete the ABC or Atanasoff-Berry Computer, considered the prototype of all later electronic computer designs. It uses binary arithmetic, logic circuits, and a form of memory. However, the ABC is not fully operational when Atanasoff and Berry are called to other duties connected with the war effort. The basic ideas of the ABC are passed on to the designers of ENIAC, who improve on them. *See also* 1939 COMP; 1945 COMP.

Salvador Edward Luria

[b. Turin, Italy, August 13, 1912, d. Lexington, Massachusetts, February 7, 1991]

A pioneer in the field of molecular biology, Luria conducted a variety of experiments using bacteriophages (viruses that infect bacteria). He believed that bacterial resistance to bacteriophages results from mutations rather than adaptations on the part of individual bacteria (the leading theory in the early 1940s). With Max Delbrück, Luria developed the fluctuation test to confirm his theory. The test became a standard tool for determining mutation rates in bacteria and viruses.



Electronics

William Bradford Shockley [b. London, February 13, 1910, d. Palo Alto, California, August 12, 1989] starts his research at Bell Labs on semiconductors. It results in the development of the transistor in 1947. On December 29, 1939, Shockley had noted in his laboratory notebook that it should be possible to replace vacuum tubes with semiconductors. *See also* 1947 ELEC.

Energy

On December 2 the message “the Italian navigator has entered the New World” is used to signal start-up of the first nuclear reactor, a controlled chain reaction in a pile of uranium and graphite at the University of Chicago designed by Enrico Fermi. *See also* 1939 PHY; 1943 ENER.

Materials

The British government begins building the domes that house radar antennas from fiberglass, one of the first large-scale applications of this composite material formed from glass fibers embedded in a polyester resin. *See also* 1937 MATR.

American chemist Frank Harold Spedding [b. Hamilton, Ontario, Canada, October 22, 1902, d. December 15, 1984], a specialist in the heavy elements, produces in November two tons of extremely pure uranium for use in developing the nuclear bomb. The material is sent in cylinders 5 cm (2 in.) high and 5 cm in diameter to Chicago, where it will fuel the first nuclear reactor.

About this time John Denoye and Bill Gross of Johnson & Johnson develop duck tape

(later rechristened “duct tape”) for the U.S. army as a waterproof tape for sealing ammunition containers. It combines cotton mesh sealed with polyurethane and a strong rubber-based adhesive. Soldiers soon find that it has many uses, including mending boots, patching tents, and repairing equipment. After the war, manufacturers will change the original khaki color to today’s familiar metallic gray.

Medicine & health

After the yellow fever vaccine used to inoculate thousands of U.S. army personnel is shown to have caused hepatitis B in many of them, a new vaccine is developed that does not require the use of human blood serum. *See also* 1937 MED.

Physics

Shoichi Sakata and Takeshi Inoue present their two-meson theory to account for the differences between the Yukawa exchange particle (now known as the pion) and the cosmic-ray meson (now known as the muon). When first discovered, the cosmic-ray meson was thought to be the particle predicted by Hideki Yukawa because of similarities in mass. *See also* 1937 PHY; 1946 PHY.

Tools

The Manhattan Project to develop a nuclear weapon (“atomic bomb”) gets under way in the United States.

Transportation

On October 3 Wernher von Braun and his staff in Germany launch the prototype of the V2 rocket, the A4, satisfac-

tory for the first time from their Peenemünde development laboratories on the Baltic coast. Powered by alcohol and liquid oxygen, the 12-ton rocket travels 200 km (120 mi) in 296 seconds, reaching a speed of 5300 km (3300 mi) per hour and a height of 97 km (60 mi). *See also* 1938 TRAN; 1944 TRAN.

LORAN (Long Range Air Navigation) begins operation for the first time along the Atlantic seaboard of North America. *See also* 1928 TRAN.

1943

Biology

Henrik Dam of Denmark and Edward Doisy of the United States share the Nobel Prize for physiology or medicine, Dam for discovery of and Doisy for determining the composition of vitamin K. *See also* 1935 BIO; 1939 BIO.

Chemistry

On April 16 Swiss chemist Albert Hofmann begins to suspect that LSD is hallucinogenic because of odd sensations that occur while he works with it. Three days later, he takes a deliberate dose and experiences sensations of time stopping while riding home on his bicycle. His landlady is transformed by his mind into a malevolent witch. A physician is summoned to care for him, but can discern no physical symptoms. The hallucinations gradually wear off, and Hoffmann induces coworkers to experience the new sensations. *See also* 1938 CHEM; 1967 MED.

Odd Hassel [b. Kristiania (Oslo), Norway, May 17, 1897, d. Oslo, May 11, 1981]

describes the possible configurations of cyclohexane and its derivatives. *See also* 1969 CHEM.

György von Hevesy of Hungary wins the Nobel Prize in chemistry for his use of isotopes as tracers. *See also* 1934 BIO.

Computers

A team headed by Alan Turing develops Colossus at Bletchley Park in England. The Colossus, designed by Thomas Flowers and Maxwell Herman Alexander Newman [b. London, February 7, 1897, d. Comberton, England, February 22, 1984], is the first all-electronic calculating device (it uses 1500 vacuum tubes). Unlike a general-purpose computer, however, Colossus is dedicated to cracking German codes — and is very good at it, possibly influencing the course of World War II.

John William Mauchly [b. Cincinnati Ohio, August 30, 1907, d. Ambler, Pennsylvania, January 8, 1980] publishes his report *The Use of a High-Speed Vacuum Tube Device for Calculating* arguing that computers using vacuum tubes would be substantially faster than the existing ones using electromechanical relays. Mauchly’s ideas are not universally accepted however because many believe that electronic circuits are not sufficiently reliable; in April, Mauchly, John Presper Eckert, and J.G. Brainerd follow this with “Report on an Electronic Diff.* Analyzer” (the footnote for “Diff.” explains it means both differential and different), which lays out the design of the ENIAC computer. *See also* 1942 ELEC; 1945 ELEC.

The Manhattan project

Several innovations in science and technology, such as radar, early computers, large liquid-fueled rockets, penicillin, and the insecticide DDT, came in response to military needs during World War II. Of these, the construction of the atomic bomb and the subsequent harnessing of nuclear energy are probably the most dramatic scientific and technical results of the scientific effort during the war — although in terms of winning the war, radar and computers were both more important.

Atomic weapon development originated with scientists.

Because of fear that Nazi Germany might develop an atomic bomb — later proven unfounded — Leo Szilard persuaded Albert Einstein to write a letter to U.S. President Franklin D. Roosevelt, in which Einstein suggested that the fission of uranium could be used to produce an atomic explosion. This letter resulted in the establishment of the largest single enterprise in the history of science up to that time. The operation, later known as the Manhattan Project, comprised 37 installations in 19 states and Canada, and employed 43,000 people. It ran on a budget of \$2.2 billion. A large number of physicists, among them the best European scientists who had fled the Nazis, joined the project. Physicists were recruited from college campuses all over the United States as well.

New cities emerged as a direct result of the Manhattan Project. Los Alamos, New Mexico, was the site where the atomic bombs were designed and built under the directorship of the physicist J. Robert Oppenheimer. The project in 1943 took over the Los Alamos Ranch School, a residential school for boys emphasizing outdoor activities. The school had an enrollment of 50 students. With new buildings constructed on the site and on nearby property, the facility came to house 5700 scientists, tech-

nicians, and their families by 1945. Oak Ridge, Tennessee, where the gaseous diffusion plant for the separation of uranium-235 from uranium-238 was located, reached a population of 79,000 in less than two years. Hanford in the state of Washington housed the nuclear reactors for the transmutation of uranium-238 to plutonium-239 and reached a population of 60,000.

Notwithstanding the enormous size of the organization, the American government succeeded in keeping the whole operation a secret. Most of the employees, and even some scientists, did not know the exact aim of the organization. Secrecy was strictly enforced. Scientists traveled under assumed names. For example, Enrico Fermi was disguised as Henry Farmer, and Eugene Wigner as Eugene Wagner. All telephone conversations at Los Alamos were under surveillance and were interrupted if the military authorities judged them a threat to security. Sensitive matters were referred to by code words; plutonium was called 49 (94 is its atomic number) and uranium "tube alloy."

The massive effort resulted in the first experimental explosion of a nuclear device in July 1945, quickly followed by the dropping of atomic bombs on the Japanese cities Hiroshima and Nagasaki on August 6 and 9, respectively, 1945. By then Germany had surrendered and Japan was nearly defeated, but the dramatic death and destruction of whole cities propelled Japan into surrendering without an Allied invasion.

After the war, the facilities continued at first to design and make nuclear weapons, but gradually Los Alamos became a national physics laboratory with many projects. Oak Ridge is also a national laboratory, but continues in the business of enriching uranium for peaceful nuclear power projects, while Hanford was dismantled (except for a museum about the Manhattan Project), becoming a major environmental problem of the 21st century.

Earth science

In Mexico farmers recognize on February 20 that a volcano, later known as Mount Parícutan, is growing in a cornfield about 200 miles west of Mexico City.

Energy

The world's first operational nuclear reactor is activated at Oak Ridge, Tennessee. *See also* 1942 ENER; 1946 ENER.

Materials

The Dow Corning Corporation in the United States begins to manufacture the first silicones. *See also* 1960 MED.

Medicine & health

Selman Waksman discovers the antibiotic streptomycin, produced by a mold that grows in soil. Previous antibiotics worked only against gram-pos-

itive bacteria, but streptomycin is effective against gram-negative bacteria. *See also* 1941 MED; 1944 MED.

Dutch doctor Wilhelm Kolff [b. Leiden, the Netherlands, Feb-

ruary 14, 1911] develops the first kidney dialysis machine. It cleanses the blood outside the body and is used for patients with nonfunctional kidneys. *See also* 1913 MED.

Shin'ichiro Tomonaga

[b. Kyoto, Japan, March 31, 1906, d. Tokyo, July 8, 1979]

Tomonaga worked out details of the way that particles of the same type interact (through exchanging a particle of a different type). His theory, called quantum electrodynamics (QED), links quantum mechanics with special relativity. His work was not known at first because of World War II. After the war, he worked against proliferation of nuclear weapons and for peaceful uses of atomic energy. He also developed a quantum-based theory of mechanical motions, known as the many-body problem.



* Physics

Shin'ichiro Tomonaga develops a renormalizable quantum electrodynamics (QED) four years before a similar theory is created by Richard Feynman and Julian Schwinger. *See also* 1948 PHY.

Otto Stern of the United States wins the Nobel Prize for physics for his work on the magnetic momentum of molecular beams.

I Tools

Microwave radar starts operating in England, detecting aircraft and putting an end to night bombing raids by Germany. RAF aircraft are also equipped with radar for intercepting ships, the first use of airborne radar. *See also* 1939 ELEC.

Russian physicist Vladimir Iosifovich Veksler [b. Ukraine, March 4, 1907, d. Moscow, September 22, 1966] develops the basic idea for the synchrotron, called phase stability (independently invented in 1945 by U.S. physicist Edwin McMillan). This idea enables construction of particle accelerators that move large groups of particles at the same speed. *See also* 1940 TOOL; 1946 TOOL.

↗ Transportation

Jacques-Yves Cousteau [b. St. André-de-Cubzac, France, June 11, 1910, d. Paris, June 25, 1997] and engineer Emile Gagnan invent the Aqualung, commonly known as scuba gear (for self-contained underwater breathing apparatus). It consists of a steel bottle of compressed air and a pressure-control valve that supplies air at normal pressure to the diver.

1944

* Astronomy

Carl von Weizsäcker revises the nebular hypothesis of the origin of the solar system in a way that causes other astronomers to accept it. In von Weizsäcker's theory, small bodies called planetesimals are attracted to each other to form the planets. *See also* 1796 AST.

Walter Baade discovers that there are two populations of stars: population I consists of younger stars found in the arms of galaxies; population II stars are older and found in the nuclei of spiral galaxies.

Hendrik Christoffel van de Hulst [b. November 18, 1918, d. Leiden, Netherlands, July 31, 2000] suggests that interstellar hydrogen must emit radio waves at a wavelength of 21.1 cm (8.3 in.). *See also* 1951 AST.

Biology

Oswald Avery, Colin MacLeod [b. 1909, d. 1972], and Maclyn McCarty [b. 1911] determine that deoxyribonucleic acid, or DNA, is the hereditary material for almost all living organisms. *See also* 1949 BIO.

Biochemist David Shemin [b. New York, New York, March 18, 1911, d. Woods Hole, Massachusetts, November 26, 1992]

uses stable isotope nitrogen-15 to determine how the amino acid glycine is incorporated into blood with metabolism. Using himself as a subject (he ingested the labeled glycine for about three days), he determines that red blood cells have an average life span of 127 days. *See also* 1940 MED.

□ Chemistry

Glenn Seaborg and his coworkers create elements 95 and 96, which they name americium (Am) and curium (Cm).

The work of Archer Martin and Richard Synge culminates in a classic paper by R. Consden, A.H. Gordon, and Martin that spells out the details of how to accomplish paper chromatography. *See also* 1938 CHEM; 1952 CHEM.

Otto Hahn of Germany wins the Nobel Prize in chemistry for his discovery of atomic fission. *See also* 1939 PHY.

↳ Communication

John Presper Eckert [b. Philadelphia, Pennsylvania, April 9, 1919, d. Bryn Mawr, Pennsylvania, June 3, 1995] and John Mauchly develop the mercury delay line store, an early form of computer memory that stores data as acoustic pulses running down a tube filled with mercury. In Janu-

ary, however, Eckert proposes the construction of a "Magnetic Calculating Machine," in which numbers and instructions would be stored on spinning disks or drums covered with a magnetizable material and read by coils placed close to its surface. It will become the form of data storage that is still most widely used. *See also* 1948 COMM.

▀ Computers

The electromechanical computer Mark I (officially the Automatic Sequence Controlled Calculator), devised by Howard H. Aiken [b. Hoboken, New Jersey, March 9, 1900, d. March 14, 1973] and a team of engineers from IBM, is completed at Harvard. Mark I uses paper tape for programming input. The computer is not especially useful because it frequently breaks down. *See also* 1941 COMP.

Herman Goldstine [b. Chicago, Illinois, September 13, 1913], meeting John von Neumann accidentally in a station, tells him about the plans of building an electronic computer, the ENIAC. Von Neumann is strongly interested and becomes involved in the design of early computer architectures. *See also* 1945 COMP.



Oswald Theodore Avery

[b. Halifax, Nova Scotia, Canada, October 21, 1877, d. Nashville, Tennessee, February 20, 1955]

The genetic revolution can be said to have started with the 1944 publication of a paper by Avery and his colleagues in which they proved that DNA — not protein, as many believed at the time — is the agent of heredity. Their work built on that of Frederick Griffith, who discovered that a "transforming substance" can be passed from one bacterium to another and cause a permanent change in the latter. Working with the same type of bacteria, Avery and his coworkers purified and tested different bacterial chemicals, eliminating all except DNA as the transforming, or genetic, material.

The first working computers

Defense needs in World War II were the driving force behind the development of the first large electronic computer built in the United States. The Electronic Numerical Integrator and Computer (ENIAC), although completed at the end of 1945, after World War II had ended, was initially designed to calculate trajectories of projectiles. Developed by the University of Pennsylvania's Moore School of Electrical Engineering for the Ballistic Research Laboratory in Aberdeen, Maryland, it was a general-purpose decimal machine containing 18,000 vacuum tubes. Its design was related to the Differential Analyzer built by Vannevar Bush, except that Bush's mechanical components, such as counters and adders, were replaced by electronic ones.

Logic was integrated into the machine's hardware, and by changing the setup of the hardware, ENIAC could be adjusted to perform different tasks. Such "programming" consisted of plugging cables into plug boards and setting hundreds of switches. Many of the vacuum tube circuits in ENIAC were derived from those used in subatomic particle counters. The computer had a very small programmable memory consisting of flip-flop circuits that could store 20 words along with several permanently wired memory circuits called function tables, which could be modified for specific calculations.

Because ENIAC used vacuum tubes instead of relays, it was about a thousand times faster in performing calculations than contemporary electromechanical machines. For example, ENIAC could calculate the trajectory of a shell in 20 seconds, faster than the 30 seconds or so that a real shell takes to reach its target.

Even while ENIAC was being completed at the Moore School, its designers, John Mauchly, Presper Eckert, and Herman Goldstine, were aware of its limitations and started work with mathematician John von Neumann on an entirely new design of computer. The basic concept, now known as von Neumann architecture, separates logic functions entirely from hardware; that is, most instructions for the execution of calculations are not permanent, called hard-wired or read-only memory (ROM), but are stored in a temporary memory called random-access memory (RAM). Instructions can be placed anywhere in memory and even modified by the computer itself when needed. Besides a random-access read/write memory, a von Neumann computer contains a central processor and uses binary numbers and Boolean algebra (a form of symbolic logic) for processing and storing data.

Unlike ENIAC, which in some ways was a parallel processor (working on different aspects of a task at the same time, or in

parallel), computers with von Neumann architecture process data serially; that is, one instruction comes after another and is executed only when the preceding one is completed. Von Neumann architecture was implemented in virtually all subsequent computers for the next quarter century. Such vacuum tube computers based on von Neumann architecture are now known as the first generation of computers. The second generation was born with the incorporation of the transistor in computer circuitry.

In 1944 von Neumann published his ideas and those of his colleagues working on ENIAC in the *First Draft of a Report on the EDVAC*. Von Neumann's ideas would have been first implemented on a planned computer to be called EDVAC (Electronic Discrete VAriable Computer). Because of patenting problems, its completion became delayed, however, and other computers became the first to use von Neumann architecture.

The EDVAC design called for a memory that would be able to store at least 1024 32-bit words ("words" in the binary numeration system consisting of 32 zeros and ones, with each binary digit (0 or 1) known as a bit). The construction of such a memory was at that time somewhat of a technological hurdle.

One type of available memory derived from the mercury delay line, a device developed for early radar to measure the time between the emission and the reception of the reflection of a radar signal. The delay line consisted of a metal tube filled with mercury. At each end of the tube a transducer was mounted. One end operated as a tiny speaker for emitting sound pulses and the other served as a microphone. A series of sound pulses could be permanently stored in such a tube by amplifying the signals picked up at one end and feeding them back at the other; the signals would travel around as in a merry-go-round. Such a delay line could store up to a thousand bits as pulses and constituted the memory of several of the early first-generation machines.

Another type of memory was derived from television technology. Information was stored on the inside of a special type of cathode-ray tube as tiny, electrically charged spots, and then read by another electron beam.

Both of these types of memory were unwieldy and not entirely reliable. They were soon replaced by ferrite-core memories that not only equipped the later first-generation computers, but also were used by the second-generation computers during the 1950s and 1960s. Ferrite-core memories use magnetic domains for recording information, a technology that, in different forms, is still the most common today. Ferrite-core ROM was also used in first-generation computers, but that was replaced by semiconductor technology in the second generation.

Jay Forrester [b. Anselmo, Nebraska, July 14, 1918] and coworkers begin to build Whirlwind, a flight simulator that is the first real-time interactive electronic device.

❖ Ecology & the environment

Raymond Cowles [b. 1896, d. 1975] and Charles Mitchell Bogert [b. 1908, d. 1992] find that desert reptiles regulate their body temperature by specific behavior patterns.

❖ Food & agriculture

An analog to coumadin, synthesized by Mark Arnold Stahmann [b. Spanish Fork, Utah, May 30, 1914, d. August 12, 2000], is patented and named warfarin (after the Wisconsin Alumni Research Foundation, which had financed research on coumadin). It is a potent poison for rats and mice, and is still used for that purpose, although now also administered to humans in smaller doses as a generic form of coumadin. *See also* 1939 MED.

❖ Materials

Lars Onsager, Norwegian-American chemist [b. Oslo, Norway, November 27, 1903, d. Coral Gables, Florida, October 5, 1976] works out the details of the gaseous diffusion method of separating uranium-235 from uranium-238 about this time. *See also* 1935 PHY; 1968 CHEM.

Σ Mathematics

Oskar Morgenstern, German-American economist [b. Görlitz, Silesia (Poland), January 24, 1902, d. Princeton, New Jersey, July 26, 1977] and John von Neumann develop the mathematical theory of games

in their *Theory of Games and Economic Behavior*. *See also* 1928 MATH.

♥ Medicine & health

After checking many soil samples for antibacterial action, Benjamin Minge Duggar [b. Gallion, Alabama, September 1, 1872, d. New Haven, Connecticut, September 10, 1956] and coworkers discover the antibiotic Aureomycin, the first of the tetracyclines. *See also* 1939 MED.

Alfred Blalock [b. Culloden, Georgia, April 5, 1899, d. Baltimore, Maryland, September 15, 1964] and Helen Brooke Taussig [b. Cambridge, Massachusetts, May 24, 1898, d. May 20, 1986] perform the first “blue baby” operation, correcting blood supply to the lungs of a female infant.

Joseph Erlanger and Herbert Spencer Gasser of the United States win the Nobel Prize in physiology or medicine for determination of such functions of a single nerve fiber as speed of transmission. *See also* 1922 MED.

❖ Physics

Isidor Rabi of the United States wins the Nobel Prize in physics for his studies of the magnetic properties of molecular beams. *See also* 1930 PHY.

I Tools

The Greenwich Royal Observatory installs its first quartz-crystal clock, providing ten times the accuracy of the previous pendulum system. *See also* 1927 TOOL.

✈ Transportation

Early in the year, the German armed forces begin to use the V-1 flying bomb, propelled by

a jet engine and controlled by an autopilot, against the United Kingdom. In September the V-2, a liquid-fueled rocket-propelled bomb, also goes into operation. The first V-2 rockets explode in London, bringing with them a ton of explosives that travel at supersonic speeds, so that the explosion occurs completely without warning, before the rocket can be heard. *See also* 1942 TRAN.

The Germans introduce a rocket-powered airplane, the Me 163B-1 Komet, into World War II, but its habit of exploding spontaneously makes it a poor weapon. Development also starts in Germany on the Ba 349 Natter, a semi-expendable rocket plane that is to be launched vertically. In the air, the Natter will launch unguided rocket missiles at enemy aircraft; the pilot, rear fuselage, and rocket motor are to return to Earth with separate parachutes. During the one known piloted launch in February 1945, test pilot Lothar Siebert will be killed, and World War II will end before the craft becomes operational. *See also* 1942 TRAN.

Igor Sikorsky builds the first modern helicopter, the VS 36 A; it has an enclosed cockpit for the pilot and adjustable pitch for the rotor blades. *See also* 1939 TRAN.

1945

★ Astronomy

Alfred Harrison Joy [b. September 23, 1882, d. April 18, 1973] discovers T-Tauri irregularly variable stars, which are thought to be very young. They occur embedded as groups in clouds of gas, suggesting that they are forming from the gas.

The first radar signals are reflected from the Moon by Hungarian Zoltán Bay [b. 1900, d. 1992] and independently by the U.S. Army Signal Corps. *See also* 1959 AST.

In mid-December the first observations are made at Jodrell Bank in Cheshire, England, using converted army radar equipment. Bernard Lovell and coworkers are looking for radiation caused by cosmic rays, but find echoes from trails made by meteors. They are able to establish that the meteors are tiny particles of dust probably produced in the tails of comets. *See also* 1939 EAR.

J.S. Hey and coworkers, using radar to observe German V-2 rockets, find that some reflections are caused by meteors. Hey then shows the reflections can be used to determine the direction of the meteor. *See also* 1932 AST.

❖ Biology

Melvin Calvin [b. St. Paul, Minnesota, April 8, 1911, d. Berkeley, California, January 8, 1997] starts using carbon-14 as a tracer isotope for investigating photosynthesis. *See also* 1940 CHEM.

Salvador Luria shows that the same spontaneous mutations occur in bacteriophages and in the bacteria upon which the phages prey, suggesting that the genetic material of the phage somehow gets mixed into the genetic material of the bacterium. *See also* 1942 BIO; 1969 BIO.

Fritz Albert Lipmann [b. Königsberg (Kaliningrad, Russia), June 12, 1899, d. New York City, July 24, 1986] discovers coenzyme A, an essential part of the chemistry of

the body, especially important in breaking down carbohydrates, fats, and portions of proteins to obtain energy for the cell. *See also* 1953 BIO.

Albert Claude, Belgian-American cytologist [b. Longlier, Belgium, August 24, 1898, d. Brussels, May 22, 1983] completes electron-microscope studies of the cell that show for the first time such structures as the endoplasmic reticulum and the details of mitochondria. *See also* 1949 BIO.

Communication

Author Arthur C. Clarke [b. Somerset, England, December 16, 1917] proposes a geosynchronous satellite. Such a satellite hovers over the same spot on Earth because it revolves at the same speed as Earth's rotation. These satellites will become the principal means of intercontinental telephone communication, starting in 1965, and later will be used to broadcast television

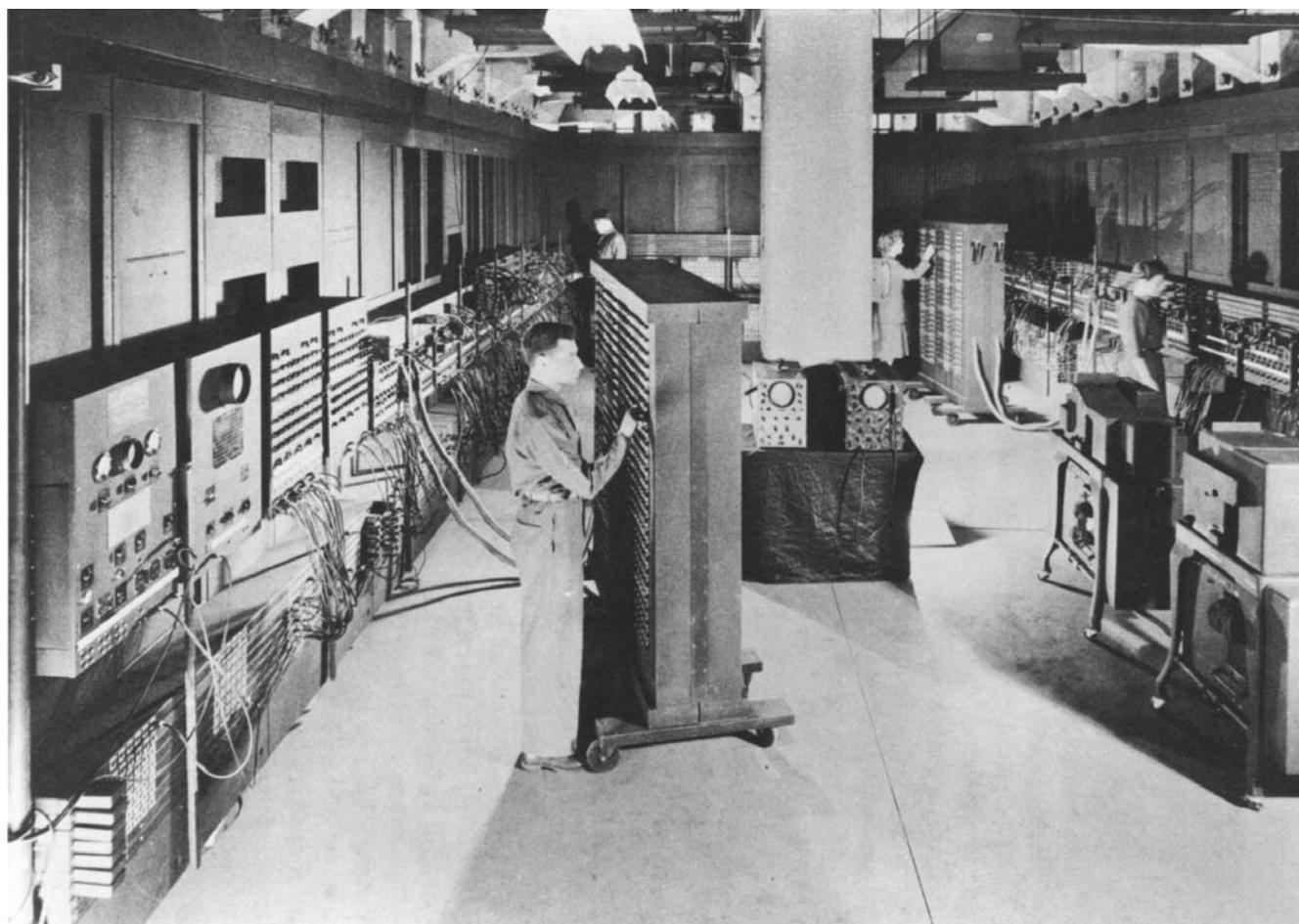
and for scientific purposes.
See also 1965 COMM.

Computers

John Presper Eckert and John Mauchly develop ENIAC, the Electronic Numerical Integrator and Computer, now generally conceded to be the first all-purpose stored-program electronic computer, although preceded by two specialized electronic computers. It will be dedicated on February 15,

1946. *See also* 1943 COMP; 1946 COMP.

Grace Murray Hopper [b. New York, December 9, 1906, d. January 3, 1992] coins the term *bug* to indicate a fault interfering with the running of a computer program. The term was derived from the discovery of an insect blocking an electric relay, but is now used for indicating a programming error.



ENIAC, THE FIRST ALL-PURPOSE ELECTRONIC COMPUTER Not only were the first computers at the end of World War II as large as a room, they were in effect rooms themselves — workers were surrounded by the parts of the computer as they input data and extracted calculations. ENIAC consisted of 30 separate units and weighed over 30 tons, forming the largest collection of interconnected circuitry then in existence. Input and output used punched cards, but programming for a new task was initially accomplished by physically connecting cables with plugs and sockets.

Alan Turing writes *Proposals for Development in the Mathematics Division of an Automatic Computing Engine (ACE)*. It contains the complete description of the ACE computer, completed at the National Physical Laboratory in England in 1949. *See also* 1940 COMP; 1949 COMP.

John von Neumann begins computer research at the Institute for Advanced Studies in Princeton, New Jersey, and writes the report *First Draft of Report on the EDVAC* (EDVAC means Electronic Discrete Variable Computer) outlining the “von Neumann architecture” for computers: a central processor, a random-access read/write memory, and the use of binary numbers and Boolean algebra. Although von Neumann places the draft in the public domain, circulation of the report prevents later workers from patenting the same ideas. The first computer to be built using the EDVAC idea is at the University of Manchester (England) in 1948. *See also* 1944 COMP; 1946 COMP.

⊕ Earth science

Paul Siple develops the first wind-chill-factor scale to take account of the cooling effect of the wind combined with a low temperature; the scale is intended to warn staff at a South Pole station about dangerous cooling conditions. Siple uses a cylinder of water suspended from a pole near a wind-speed indicator positioned about 10 m (30 feet) off the ground to obtain his data. Later the U.S. Weather Bureau begins to provide wind-chill data on cold, windy days in North America. *See also* 2001 EAR.

⊖ Food & agriculture

Herbicide 2, 4-D, the first modern plant poison, is introduced. *See also* 1940 FOOD; 1955 FOOD.

Percy L. Spencer [b. 1894, d. 1970] of Raytheon, having observed that a microwave device in a Raytheon laboratory melts a candy bar in his pocket and having experimented almost immediately with microwaved popcorn,

patents the “high frequency dielectric heating apparatus” that we know as the microwave oven. In its original form it is a giant, costly device aimed at restaurant use. *See also* 1937 ELEC; 1955 FOOD.

Artturi Virtanen wins the Nobel Prize in chemistry for his invention of fodder preservation. *See also* 1929 FOOD.

♥ Medicine & health

Fluoridation of a water supply to prevent dental decay is introduced in the United States in Grand Rapids, Michigan. *See also* 1874 MED.

Sir Alexander Fleming, Sir Howard Florey, and Ernst Chain of England win the Nobel Prize for physiology or medicine for the discovery of penicillin and research into its value as a weapon against infectious disease. *See also* 1928 MED; 1940 MED.

⊗ Physics

Felix Bloch and Edward M. Purcell independently demonstrate nuclear magnetic resonance; atomic nuclei with

aligned magnetic moments that are placed in a magnetic field absorb electromagnetic waves selectively. *See also* 1952 PHY.

Wolfgang Pauli of Austria wins the Nobel Prize for physics for the Pauli exclusion principle for subatomic particles. *See also* 1925 PHY.

I Tools

On July 16 the United States explodes the first nuclear weapon based on uranium-235, known as the atomic bomb, at 5:30 a.m. local time at Alamogordo air base in New Mexico. On August 6 a similar device is dropped on Hiroshima, Japan, killing 118,661 immediately (many also died later from radiation sickness). This is followed by another nuclear weapon, a plutonium-based fission bomb, used against Nagasaki, Japan, on August 9, killing 73,884. This exhausts the U.S. supply of “atomic bombs,” although this fact is kept secret. The Japanese soon surrender unconditionally. *See also* 1939 TOOL.

Scientists and defense

The outcome of World War II was determined to a large extent by certain technologies developed by the Allied forces, especially the United Kingdom and the United States.

Radar produced by powerful tubes called magnetrons gave the British an advantage in the air over the Germans. The United States obtained the magnetron from the British and equipped their warships with radar, gaining an advantage over the powerful Japanese navy. The United States and British worked together at the Radiation Laboratory in Cambridge, Massachusetts, to improve radar throughout the war. The British also created the branch of science known as operations research that enabled them to allocate resources and even to aim bombs better.

Another advance for the United Kingdom was the first practical electronic computer, used successfully to decipher coded German messages. American computers were built as a part of the war effort, but the first was finished too late to have any impact.

On the other side, German scientists were successful in developing rocket-powered bombs and aircraft, but these did not produce strategic successes. The V-2 rocket bombs terrified Londoners near the end of the war, but were too inaccurate to use to knock out militarily important targets.

The United States finished the war with the atomic bomb, instrumental in causing Japan to surrender without being invaded.

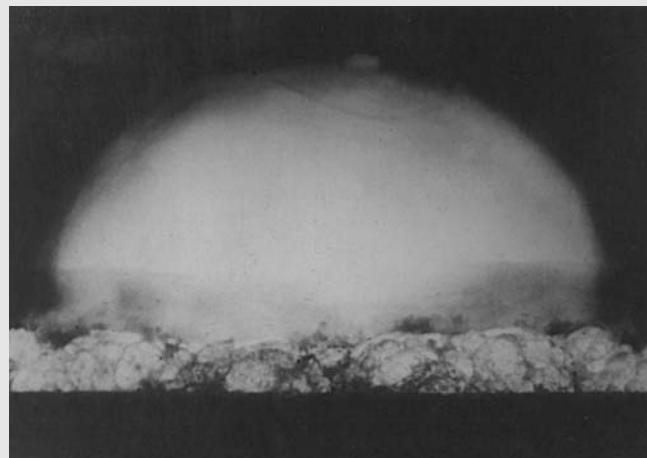
Convinced by such wartime successes, governments of large industrialized nations started funding military research and development (R&D) on a very large scale, initiating what subsequently became known as the arms race. The Manhattan Project, which

developed the first U.S. atomic bomb, had demonstrated that theoretical scientists could play an important role in defense. Therefore, the military started funding large numbers of basic research projects at universities. The U.S. Office of Naval Research funded research projects in biology and oceanography. The U.S. Defense Advanced Research Projects Agency (DARPA) was for a long time virtually the only agency funding research in artificial intelligence.

Some scientists who had worked on nuclear weapons later regretted their participation. As World War II became a memory instead of a living presence, many scientists avoided defense work. The Strategic Defense Initiative (SDI — also known as star wars), introduced in 1983, kindled a debate among U.S. scientists on whether universities should be involved in military research projects at all. Many scientists' objections were based on the principle of not wanting to see science become a tool of destruction. Others decried the secrecy rules imposed on scientists at universities that participated in SDI projects.

Despite this, the cold war arms race and SDI recruited large numbers of scientists and engineers. By 1984, for example, 14 percent of the total of 4,000,000 scientists and engineers in the United States worked in military R&D. However, the end of the cold war during the late 1980s reduced levels of weapons research both in the East and West. In the United States, several federal weapons laboratories turned to work on civilian research projects. Russia after the cold war had little money to invest in paying scientists to develop weapons. In some cases, the United States paid Russian scientists to help dismantle the Soviet weapons programs.

Although federal funding for R&D was reduced in the United States, in 2003 some 49 percent of federally funded research continued to pass through the Defense Department, while other less publicly acknowledged research was supported by defense-related parts of the government, such as the National Security Agency or the Central Intelligence Agency.



FIRST ATOMIC BOMB EXPLODES AT ALAMOGORDO The initial explosion of a nuclear-fission bomb, before the mushroom cloud forms, is dramatic by itself. The picture was taken just 0.016 seconds after the blast started. Already the fireball is about 300 m (1000 ft) across.



Big Science and the Post-Industrial Society: 1946 through 1972

During World War II scientific development was vastly accelerated as a result of the war effort.

Among the discoveries and inventions that reached practical application as a result of the war (although they all had roots in prewar research) were synthetic rubber, radar, DDT, penicillin, nuclear fission, jet-powered aircraft, helicopters, ballistic missiles, and the electronic digital computer. After the war, this technology quickly reached the public in developed countries. The cumulative impact of the advances changed the environment in fundamental ways. There had been no period of comparably swift technological change since the Industrial Revolution or perhaps not even since the adoption of farming some 10,000 years earlier.

In some cases, progress in inventions or discoveries not directly involved with the war effort was slowed rather than accelerated. One such example is that of television. But after the war, when the growth of economies resumed, television quickly became ubiquitous in advanced countries.

Although the technological advances were phenomenal, the scientists of the late 1940s were not very accurate in foreseeing which changes these would bring about in the postwar period. Some predicted that helicopters would replace automobiles. No one foretold that DDT would be banned in the United States after more than 20 years of use. The real significance of the electronic computer was misunderstood in the immediate postwar period (one prediction was that by the 1980s, a few large companies would own their own computers), while

many expected nuclear power to solve all of the world's energy problems.

In pure science as well, the unexpected continued to occur. Few scientists in the brief optimistic period at the end of World War II would have predicted that by 1972 the beginning of the universe would be identified; the secrets of heredity would be unraveled; the discarded continental drift theory would resurface as the most vital part of earth science; many famous conjectures in mathematics would be resolved; and the zoo of elementary particles would almost make sense.

The cold war and new technology

Although the success of science would seem to cause most people to regard science in a positive fashion, it is far from clear that that is the case. The development of nuclear weapons led to a perception by some of scientists as amoral seekers after knowledge. Among scientists themselves there was considerable horror at what they had accomplished. It was apparent that nuclear weapons could destroy life on Earth, especially after the development of fusion bombs. Some scientists formed the Union of Concerned Scientists to work against the misuse of nuclear energy. Others refused to work on defense-related projects. The public perception of nuclear energy as dangerous was further enhanced by a number of accidents in nuclear power plants.

The fission and fusion bombs developed in the 1940s and 1950s were so much more destructive than earlier weapons that it was hard to relate them to ordinary explosives. Furthermore, the new bombs not only blew things up

and started massive fires, they melted or vaporized materials that were thought to be completely stable; seeing a photograph of the shadow of a human permanently in place on a concrete wall after the bombing of Japan with fission devices reminded viewers that this was a brand new force. On top of everything else, the area bombed was altered by becoming radioactive. It was already known that radioactivity could cause people to sicken and die. Even scarier, it could affect future generations by causing mutations of germ cells.

As if the threat of the new bombs were not enough, the long-range rockets developed during the war were soon improved to where the rockets could drop bombs almost without warning thousands of miles away from where they were launched.

For the first time since the first millennium CE, a great many people began to believe that the end of life on Earth was imminent. The means were clearly identified as the result of science and technology, even though the political situation at the time, known as the cold war (confrontation without major armed conflict between Western nations and communist countries), was the major occasion for concern. But it was also evident that the cold war might have been an ordinary war if not for the weapons of mass destruction and means of delivery that prevented full-fledged war between the United States and the Soviet Union (Russia).

To some extent, the cold war encouraged science in ways similar to a real shooting war. The two sides each tried to outdo each other in satellites and space probes, a competition called the

Big Science and the Post-Industrial Society: 1946 through 1972

Space Race. Competition between powers, especially the United States and the Soviet Union, for successes in space seemed for a time to be what American philosopher William James had termed “the moral equivalent to war.” In the United States concern about communist aggression led to increased federal funding for science and for science education. Government became the major funding agency of scientific and technical research and development in the United States; and in the Soviet Union, the military became the largest employer of engineers and scientists.

Big science

The way science was conducted also changed after (in some instances during) World War II. Before that time, almost all advances could be ascribed to an individual working on his or her own or with a single partner or mentor. After World War II, it was the exception rather than the rule that a concept or device would be developed by a single scientist — except for studies of whole organisms and their behavior and for mathematics, which remained the preserve of the individual for several decades. In other disciplines, teams did it all.

There were good reasons for this shift. After 1945 it was not possible to have a major program in particle physics without expensive particle accelerators and detectors. To a lesser degree, similar equipment needs were felt in other “hard” sciences. Expensive equipment must be shared to be affordable. Even in the life sciences, the cost of science soared. In addition, a phenomenon often needed to be viewed from many angles before it could be understood. Interdisciplinary teams fulfilled this requirement.

Science became big in another way, also. Many more people became scientists, both in actual numbers and as a percent of the world’s population, than

there ever existed in the past. The reasons for this growth are complex. For one thing, the world’s population is larger, and much less of it is needed to produce food and manufactured goods, freeing more of the population for other pursuits. More institutions perceived the need for scientists on their staffs. By the 1980s, half of all the scientists in America were employed in business or industry.

Most scientists, however, were producing a lot of knowledge, so much that no one could keep up with the details and only a few generalists could even follow the major trends in all areas of science. This resulted in another trend, specialization.

Specialization and changing categories

Over the history of science since the Renaissance, as the totality of scientific knowledge has grown, scientists have specialized more and more. Newton investigated all aspects of the physics of his time and also contributed greatly to mathematics. Einstein limited his work to theoretical physics, but he contributed to virtually all parts of that field. A theoretical physicist today must specialize in one field only — either particles, materials, nuclear physics, astrophysics, biophysics, or perhaps just gravity. Only the very best can bridge the gaps between even two of these specialties. The same situation is true in other parts of science as well. A “whole-organism biologist,” who studies such whole organisms as birds or plants and looks at behavior or anatomy or taxonomy, has little in common with a molecular biologist, who studies how events happen within cells. This kind of dichotomy was not so significant in prewar science.

At the same time as there has been specialization, there has also been a merging of disciplines. Astrophysics and biophysics are only two examples. Chemistry has been especially parti-

tioned into new disciplines. On one side, chemistry has increasingly become a part of physics, as physicists have redeveloped chemistry from the proton, neutron, and electron on up to substances. In another direction, biologists have gradually moved into chemistry in their search for how living things work at the molecular level. One result is that much of what used to be chemistry is materials science (physics) and biochemistry (a part of biology). The leftover part is largely chemical engineering, for much of the theoretical part of chemistry has been taken over by the materials scientists.

In a few cases, new sciences have emerged that were not perceived as separate disciplines to any significant degree before World War II. Ecology existed, for example, but there were no professional ecologists as such; they were biologists who specialized in ecology. Ethology, the scientific study of animal behavior, and limnology, the study of lakes and freshwater systems, are similar cases. In physics, the separation of nuclear and particle physicists did not take place until after the war. Some astronomers (prewar) became cosmologists (post-war), and so did some physicists. Space science is still emerging. There are even sciences with nothing known at present to study, such as exobiology, the study of extraterrestrial living things.

Technology changes society

Since the Industrial Revolution, technology has exerted an important influence on the way people live. While the Industrial Revolution initiated a general movement of the population toward cities, the availability of the automobile had the reverse effect: People started leaving cities and living in the forever sprawling suburbs. Traveling by car, especially in the United States, became very cheap and also contributed to the decrease in rail passenger services.

Technology also influenced and even rearranged the traditional divisions between professions and the work force. The introduction of automation in manufacturing allowed many manufacturing processes to be done by less skilled workers. Also, the new, more complicated technology associated with automated manufacturing required more know-how. Technical know-how became the domain of an increasingly powerful but small group of people. During the 1960s and 1970s, automation also reached the office, with the same results. For example, when the first computers appeared in industry, banking, and administration, they were completely mystifying to the average worker, and the few computer "specialists" gained considerable earning power. Meanwhile, some of the tasks secretaries and bookkeepers normally do could now be handled by word-processing and spreadsheet programs that a manager could use himself or herself.

The main consequence of increasing automation was that the middle group of skilled workers lost ground. The work force split into two groups: the specialized worker who had the knowledge to deal with sophisticated and automated machinery, and the unskilled worker still required for many menial tasks, such as feeding pieces to be transformed to automatic machines.

There are two very different kinds of technology. One is specific to certain problems — for example, Velcro. The other is a generalized new technology that affects many different fields of endeavor — such as the laser. A few technologies are somewhere in between, such as liquid-crystal displays. The period after World War II is particularly rich in all varieties of new technology.

The specific technologies are the ones that perhaps change everyday life the most. Before 1946 cars did not have tubeless or radial-ply tires, power steering or power brakes, or fuel injection,

not to mention some of the advanced features available in models today. Remember carbon paper? Now we have copying machines. Think of life without compact discs and DVDs, or audio or video cassettes, battery-powered watches, microwave ovens; fax documentation, permanent press! These advances change the texture of everyday life.

Major advances

ANTHROPOLOGY Theories of physical anthropologists changed greatly during the period. Before World War II it was generally assumed that the main characteristic of hominids was the large brain relative to the body. In part this was based on the Piltdown hoax, which combined a modern human braincase with an orangutan jaw, and on human vanity. When Piltdown man was discredited in 1953 and evidence accumulated that the small-brained australopithecines walked erect, the definition of hominid shifted from the brain to the legs and pelvis. Most physical anthropologists of the 1960s believed that the australopithecines gradually evolved into the earliest humans; but the discovery in the 1970s that the earliest humans and australopithecines occupied the same territory at the same time changed that idea.

ARCHAEOLOGY Increasingly, archaeologists took care to see that their work was scientifically valuable and not just a search for trophies and treasures. For example, parts of sites were deliberately left untouched so that future generations of archaeologists, who might have better tools, could investigate the undisturbed portions. One of the main trends in archaeology emerged from the invention of better diving equipment by Jacques-Yves Cousteau. Scuba gear made it possible for archaeologists to expand their work into the sea, where many essential artifacts and even whole villages have been preserved.

ASTRONOMY Although all phases of astronomy have advanced continuously since World War II, it is convenient to relate the advances by decade. In the 1940s the Hale telescope was put into operation at Mt. Palomar in California. It remained the best optical telescope in the world throughout this period. In the 1950s radio astronomy began to probe the universe, which was found, by other means, to be twice the size scientists had thought it to be. It was not clear in those days whether the universe existed in a steady state with continual creation of matter or whether it had begun in a big bang. The 1960s saw the first exploration of nearby space with satellites and space probes, as well as the surprises of quasars and pulsars. The big bang theory of creation became dominant as new evidence surfaced. X-ray and neutrino astronomy joined optical and radio approaches.

Since 1957, when the first artificial satellite was put into orbit about Earth, space technology has been most useful as a scientific tool when vehicles without people aboard were used. Small space probes reached Venus, the Moon, and Mars during this period. Satellites detected belts of radiation around Earth, the solar wind, and giant magnetic fields in space.

BIOLOGY Biology made the most dramatic progress of any science after World War II, especially biology at the level of the behavior of individual molecules. There were also dramatic gains in understanding the behavior of animals, especially primates, that emerged from careful studies in the wild. The most notable development in biology, however, was the rise of genetic engineering.

A little more than 50 years after biologists became aware of Gregor Mendel's laws of heredity, James Watson and Francis Crick found the key to how these laws work. The discovery of the structure of DNA almost immediately led to a new understanding not only of heredity, but also of how proteins are

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made and how viruses affect the body. The understanding would continue to bear fruit in the years after 1972.

CHEMISTRY To many people chemistry gradually changed from friend to enemy in the postwar period. As chemists developed new herbicides and pesticides, they helped create the immense production of food and fibers with greatly decreased labor; but as fish kills and occasional problems with cancer among some who worked with the chemicals impinged upon people's consciousness, many felt it necessary to reduce the dependence on such chemicals. Similarly, chemists developed additives that prolonged food shelf life, made it cheaper, or improved its color; but again people came to view such additives with suspicion as part of a broad-based concern about their health risks.

Although of little immediate practical use, the most dramatic story in chemistry during this period was success in forming compounds with some of the noble gases, heretofore believed not to enter any form of molecule.

COMMUNICATION The postwar years saw enormous growth in communications technology. Television spread around the world in less than a decade, and radio broadcasting became a suitable medium for the new high-fidelity recordings as a result of the introduction of frequency-modulation (FM) radio. Microwave technology, initially developed for radar, became used for the transmission of telephone conversations over land. The telephone systems of cities were linked by microwave transponders, easily recognizable by their dish- or horn-shaped microwave antennas, which allowed a strong increase in message capacity. Coaxial cables also increased the capacity of telephone lines drastically. Telephone traffic between Europe and the United States initially depended on short-wave radio. The first transatlantic telephone

cable, in 1956, followed by several other cables in the 1960s, made a telephone call between London or Paris and New York less of an exotic event, although true ease in international calling did not come until satellite transmission began.

Communications satellites, introduced during the 1960s, expanded enormously telephone communication links between and even within continents. The first communications satellite, *Echo I*, was a huge metalized balloon that circled Earth and that could relay radio communications by reflecting radio waves. Subsequently, active communications satellites were placed in geostationary orbits; their operation could be compared to the microwave transponders used on Earth to link cities.

COMPUTERS Early computers with vacuum tubes used too much energy and were "down" most of the time. The 1940s computer was programmed by hard wiring and its storage memory was a host of magnetic core devices. It was not until 1956 that a computer language was developed; the keyboard for entering data came 11 years later; and it was another three years before data could be stored on floppy disks.

The transistor, which came along a couple of years after the war, solved many computer problems. The reliable transistor's descendants made computers cheaper and smaller at an astonishing rate. Although the progress in electronic components affected all kinds of machines, the development of computers and digital electronics can be termed a technical revolution. Computers progressed from cumbersome electronic renderings of electromechanical machines to highly flexible and user-friendly universal machines. Their application spread from number crunching into all areas of human activity, such as administration, banking, defense, civil aviation, space exploration, and petroleum exploration. Software, which was nonexistent when the

first computers were built, developed quickly, and from mid-1950 on several high-level computer languages became available. The 1960s and 1970s can be termed the era of the mainframe, large computers with much hardware, typically housed in a computer center and operated by computer specialists.

CONSTRUCTION One of the main developments in architecture during this period was the modern "glass" office building — actually a steel and reinforced concrete building with a curtain wall or a supported wall of glass. Often the glass was tinted to make the building look blue or golden. In New York City the Lever House and the Seagram Building, only a few blocks apart on Park Avenue, started the trend. Soon almost all office construction in the heart of major cities around the world used similar designs, creating a uniformity that was known as the International Style. Such buildings were often raised by ingenious construction techniques featuring giant cranes that rose with the building.

At the same time, a more modest revolution was taking place at the level of personal housing. Ever since Roman times, people had increasingly moved into large multiple dwellings (row houses or apartment houses) in cities. After World War II the first reversal of such urban migration took place as builders established inexpensive, often prefabricated, housing developments outside of cities. Now people in Western countries could afford to leave the giant multiple dwellings for a home of their own, and large numbers took advantage of the opportunity. The suburbs came into being. Soon the toll on the inner city began to be felt, especially as shopping centers in the suburbs began to satisfy the basic needs of the people who had moved from the city. In the communist world, however, large apartment buildings continued to proliferate.



LEVITTOWN — ONE OF THE FIRST POSTWAR SUBURBS The first houses in Levittown in New York in 1947 cost buyers as little as \$8000 because they were built with mass-production techniques developed by the U.S. armed services in World War II. As the suburb grew, the builder introduced models with variations that reduced the uniform appearance, although there were still only two basic models in the early 1950s.

EARTH SCIENCE The period after World War II saw a revolution in our basic understanding of Earth's crust. In the 1950s and 1960s, geologists developed the idea that the crust of Earth was broken into a number of large plates that move relative to each other. This theory explained such features of Earth as the locations of many earthquakes and volcanoes, of most mountain ranges, and of trenches and rifts on the floor of the ocean.

Meteorology is another part of earth science. While weather forecasts improved as a result of data from satellites and radar as well as better computers and computer models, in 1961 Edward Lorenz established that very small changes in initial conditions result in large changes in the weather. Consequently, medium-term weather prediction (more than a week and less than a year) probably can never be certain. Scientists studying

long-term changes, however, became concerned that gases released by human activity were causing major changes in the atmosphere. One such change, the greenhouse effect, may cause temperatures to climb worldwide as a result of carbon dioxide and other gases that trap heat in the atmosphere the way that the glass walls and ceiling of a greenhouse trap heat.

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ECOLOGY & THE ENVIRONMENT Environmental problems caused by industry have existed since the early times but they became extensive during the 19th century. Instead of localized pollution problems, industrialized centers, such as England's Midlands, experienced regional pollution. Even then, however, the fact that industrial pollution formed a threat to human lives became fully understood only after World War II. Earlier in the 20th century, burning coal for heating and the generation of electricity was the main cause of atmospheric pollution. Sometimes this had catastrophic consequences, such as the notorious London smog — although the danger of smog was not recognized until a particularly bad episode in 1952 took 4000 lives.

The advent of oil product and natural gas as primary energy sources introduced new pollutants into the atmosphere. Again the consequences were sometimes severe, such as the photochemical smog in Los Angeles, mainly caused by the exhaust fumes from cars. At the same time, concerns arose about the natural reserves of energy sources. It became clear that oil and gas reserves were in danger of becoming depleted.

Other events also showed that the new technology was not necessarily good for the environment. Nuclear wastes exploded in the Soviet Union. DDT killed birds as well as mosquitoes and flies, an effect that led to the founding document of the American postwar environmental movement, *Silent Spring* by Rachel Carson in 1962. In the years following *Silent Spring* the U.S. Congress responded to these concerns with new laws protecting the air, wilderness, and endangered species in the 1960s. By the start of the 1970s the environmental movement had become a political force, celebrating Earth Day by focusing on ways to protect the environment.

In an international response to the

same concerns, a group of scientists and economists founded in 1968 the Club of Rome. The Club of Rome sponsored a team at the Massachusetts Institute of Technology (MIT) to study the future development of several aspects of human activity, such as population growth, food production, industrialization, nonrenewable resources, and pollution. Their report, *The Limits of Growth*, published in 1972, was based on computer models; it predicted catastrophic developments, such as a shortage of food and other resources, if the then existing trends continued. Fortunately, many such predictions have proven to be too pessimistic.

In pure science, mathematics was employed extensively by ecologists to describe the statistical behavior of communities of animals and to explain altruism and other traits in the controversial new discipline of sociobiology.

ELECTRONICS Until the mid-1950s all electronic devices functioned with vacuum tubes, and early computers were sometimes equipped with several thousands of them. Failures were frequent because of the limited lifetime of the heating filaments in vacuum tubes. Vacuum tubes were also power hungry, and the impacts of electrons produced excessive heat.

The invention of the transistor in 1947 by John Bardeen, Walter Brattain, and William Shockley revolutionized electronics. The transistor became an ideal substitute for the vacuum tube for most purposes because it was more reliable, required much less power, and produced little heat. Electronic devices based on transistors could be built in compact sizes, yet with greater complexity of design, making miniaturization practical for the first time. One of the first civilian applications of transistors was in hearing aids.

The first computers built with transistors appeared in the mid-1950s. By

1959 practically all computer manufacturers used transistors throughout, making computers much smaller and more reliable. During the 1960s the transistor displaced vacuum tubes in television sets, radios, stereographic photographs, and most scientific instruments.

In the early years of their development, transistors could not replace all functions performed by tubes — for example, in the 1950s no transistors were available that could operate at very high frequencies. But by the end of the 1960s, the capabilities of transistors generally surpassed those of vacuum tubes, even in high-frequency applications, such as high-fidelity amplifiers. The transistor, because of its small size, is also more suitable for incorporation into printed circuits than are vacuum tubes. A printed circuit uses printing technology to deposit a wiring pattern in conducting material on a board, thus making it possible to reproduce wiring by mass production. Printed circuits with transistors soon were used in all electronic devices, not only because they could be mass produced, but also because they were sturdy and the wiring errors of manual production were eliminated.

A development as important as the introduction of transistors was that of the integrated circuit, a kind of printed circuit that goes beyond boards. Developed independently by Jack Kilby at Texas Instruments and Robert Noyce at Fairchild Semiconductor, the technique consists of embedding electronic elements and connections on a small wafer of silicon. In this way several transistors can be placed on a chip, increasing miniaturization and reliability further by decreasing the number of components to be placed on a printed circuit board. Using photolithographic techniques, yet another borrowing from printing technology, such chips could be produced cheaply in quantity.

Soon they replaced complete circuits, such as logical gates for computers, or complete electronic amplifiers. The greatest breakthrough in chip technology came during the early 1970s with the introduction of the first computer memory chips and microprocessor chips, heralding the development of the microcomputer a few years later.

ENERGY Coal had been the main energy source in the industrialized world since the Industrial Revolution. This situation changed during World War II. Although coal remained the single largest energy source until about 1970, its place has since been taken over by petroleum. Natural gas and, in Eastern Europe, lignite are two other fossil fuels that today form a substantial part of the energy supply. Because of discoveries of natural gas reserves, coal gas was phased out.

Petroleum (oil) became widely used because it was easy to handle and a cheap source of power; it displaced coal in most countries. Petroleum also was the starting material for a large number of new chemical products, of which plastics became the most important. The chemical industry became the fastest growing industry during the postwar years.

During the 1950s oil became in many countries the main source of energy for domestic heating. Oil is not only easier to manipulate and to transport than coal, but it became much more available because of several new techniques developed for exploration on land and at sea, and for obtaining it at offshore locations. Offshore drilling for oil had already started before World War II; the first offshore oil was obtained in 1947. During the 1960s and 1970s, a substantial part of oil was obtained from using drilling platforms at sea (almost 15 percent of all the oil supply in 1970).

The atomic bomb had convincingly proved that enormous amounts of

energy can be liberated by nuclear reactions. To use this energy for peaceful purposes, the energy must be released in a controlled way. This can be done by slowing down nuclear chain reactions so that they occur in a sustained but constant rate. In a nuclear chain reaction, neutrons produced by fission reactions cause new fission reactions to occur; by absorbing these neutrons with a substance called a moderator, it is possible to fine-tune the fission reaction so that the chain reaction takes place at a constant, but slow, rate.

The first nuclear reactors developed in the 1940s and 1950s used uranium as fuel and graphite as moderator; they were cooled by carbon dioxide gas. These reactors were mainly built in Europe, especially France and England. In addition to using the reactors to generate power, both nations also used them as a source of plutonium for the development of nuclear weapons. The United States developed pressurized water reactors. Water, maintained under pressure to prevent it from boiling, serves simultaneously as moderator and cooling fluid. The heated water is led through separate steam generators (heat exchangers) that produce the steam for driving the turbines. Such reactors do not generate significant amounts of plutonium. There are also boiling water reactors, in which steam is generated in the reactor itself, and reactors based on the properties of deuterium oxide (heavy water).

FOOD & AGRICULTURE Although the farming community had long resisted large-scale production techniques, postwar agriculture was mainly marked by increased mechanization. Tractors came into general use, and livestock farming became more automated. The use of improved seed and of herbicides and pesticides also made farming much more efficient. A consequence of this development is that the farming population started decreasing strongly in

Europe and the United States, a trend that continues today.

Concern about herbicides and pesticides in farming, including the possible consequences to health as well as loss of effectiveness on repeated use, led to the development of organic farming. Thousands of farmers began to switch to agriculture based on the use of organic compost, crop rotation, shallow plowing, and the avoidance of chemical fertilizers, pesticides, and herbicides, a trend that became much more prominent after 1973. Of course, much organic farming is simply a return to agricultural practices of earlier in the 20th century.

Around the developed world, modern transport has meant that almost all fruits and vegetables became available year-round. For example, Northern Hemisphere nations obtain seasonal produce from the Southern Hemisphere, and vice versa. Even within large nations, such as the United States, most food was no longer produced locally, but was shipped all over the country from a few locations. The increased use of commercial greenhouses has led to the cultivation of a much wider variety of vegetables, such as tomatoes, in the northern countries of Europe.

MATERIALS Petroleum has not only played an important role in the supply of energy, but it has also become the most important raw material for an extraordinary number of new products, including plastics, solvents, resins, and detergents. During the 1960s, the chemical industry grew three times as fast as the total growth of industries. The chemical industry has had a large influence on daily life. While before World War II, most objects in use had a natural origin — wood, glass, and rubber are examples — after the war, similar manufactured objects were made of plastics and other synthetic materials. Cotton and wool were displaced by

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polyesters and nylon, and the chemical industry became one of the major suppliers of the textile industry.

MATHEMATICS Much of mathematics after World War II became so abstract that nonmathematicians have great difficulty in following the results. Some important proofs of long outstanding problems were produced. Georg Cantor discovered late in the 19th century that there are many different-sized infinities. His continuum hypothesis conjectured that two particular infinities constructed by different processes are the same size. Paul Cohen showed in 1963 that Cantor's continuum hypothesis concerning infinite sets is neither consistent nor inconsistent with the generally accepted basis of mathematics. Cohen's work (which was built on a 1940 proof by Kurt Gödel) showed that one can choose whether the two infinities will be equal or not equal. About the same time, Cohen (again building on Gödel's earlier work) showed that a widely used axiom in set theory has a similar position in mathematics.

More important than proofs of individual theorems was the development of fruitful new concepts in mathematics that could then be used to solve a range of problems. The best known of these during this period was probably catastrophe theory, originally put forward by René Thom. Instead of dealing with smooth processes, such as continuous acceleration, catastrophe theory treats events in which "the straw on the camel's back" causes a complete change of state.

MEDICINE & HEALTH The interaction of medicine and biology, especially molecular biology, became so close that it is sometimes difficult to tell where one ends and the other begins. On the other hand, many innovations are pure medicine with little or no input from molecular biology. These include organ transplants; endoscopy and related techniques (for example, angioplasty, in

which a tube inserted into an artery carries a balloon or laser used to flatten or remove arterial plaque); amniocentesis and other methods of diagnosing and treating the fetus; ways of handling fertilized human eggs to produce viable children; artificial substitutes for skin; cochlear implants to aid hearing; kidney dialysis; ultrasound scanning; and a variety of new vaccines.

The introduction of penicillin and other effective antibiotics had a big influence on the practice of medicine. Many diseases that had been difficult to treat, such as tuberculosis and syphilis, became controllable. Researchers also developed several wide-spectrum antibiotics that could fight many different species of bacteria. A better understanding of immunology led to the development of new vaccines, especially vaccines against viral diseases such as influenza, measles, and polio. It also led to the better understanding of immunological rejection mechanisms, and the development of drugs that prevent organ rejection. These developments made organ transplants possible. The most spectacular achievement was the first transplant of a human heart by Christiaan Barnard in 1967. Surgeons also started to perform liver and lung transplants around that time. Advances in endocrinology led to the development of the contraceptive pill.

Just as discoveries of the endocrine system and of vitamins in the earlier part of the 20th century revolutionized the understanding of disease, a new understanding of the immune system that developed after 1945 produced major changes in our knowledge of how some diseases are caused and how they may be avoided. The discovery of blood types, artificial immunity with killed or weakened germs, and allergic shock in the late 19th and early 20th centuries suggested that some substances or processes in the body become activated when exposed to

"foreign" proteins. After World War II, Mcfarlane Burnet and Peter Medawar showed that the reaction against foreign proteins is developed largely after birth. The study of the immune system then unraveled an increasingly complex network of interacting cells and proteins. Many diseases, including some types of arthritis and diabetes, were found to be caused when the immune system attacks a part of the self.

Developments in electronics also contributed to medicine. The pacemaker, introduced in 1960, allowed regulation of the heartbeat by synchronizing it with electrical pulses. The combination of computer technology with X-ray diagnosis led to the development of the computerized tomography scanner (CT scanner).

PHYSICS World War II ended with two nuclear fission bombs ("atomic bombs") used as weapons, preceded by a single test earlier in 1945. Physics clearly had an important place in military matters, and funding for large projects in physics has continued, especially in nuclear and particle physics. More recently, governments have realized how important materials science is to them and the economy. This is the branch of physics that produced the transistor and its descendants, as well as the laser. Funding for physics has contributed to a remarkable period of growth since the war.

Discovery of the Lamb shift in 1947, just before a major conference of leading physicists at Shelter Island, New York, led to the solution of mathematical problems that had surfaced in the study of atoms and subatomic particles. The mathematical theory that resulted is quantum electrodynamics (QED), often called the most accurate theory in physics.

Just as QED was being developed, however, scientists studying cosmic rays began to find new subatomic particles that did not behave as predicted — for one thing, they did not decay into other

particles as fast as theory called for. The reason for this strange behavior was worked into theory and christened “strangeness,” the beginning of a trend in physics toward whimsical names, from quarks and flavors to WIMPs (weakly interacting massive particles). Strangeness and the newly discovered strange particles were fit into a classification scheme, somewhat like the earlier periodic table, called the eightfold way. The eightfold way, like the periodic table, enabled prediction of previously undiscovered entities. When the predicted omega-minus particle was found in 1964, the eightfold way was viewed as confirmed.

The eightfold way was developed by Murray Gell-Mann on the basis of abstract mathematics, not on the basis of some physical understanding of why it should work. The same year that the eightfold way was confirmed, Gell-Mann introduced his physical explanation, called the quark model. The quark model explained most particles as combinations of other particles, called quarks, that have fractional charges (omitted from the quark model were electrons, neutrinos, and their relatives). The quark model was even more successful than the eightfold way.

The strange particles of 1947 also started another major line of thinking. Again, the problem was that some particles decayed in ways that violated prevailing theories. Chen Ning Yang and T.D. Lee concluded that this decay problem could be explained if nature distinguished between right and left in certain instances. A team of experimenters headed by Madame Chien-Shiung Wu showed that the Yang-Lee idea was correct.

The success of Gell-Mann in using a mathematical theory to reach the quark model inspired others to work with similar mathematical ideas — specifically a branch of mathematics called group theory — to explain the particles left out of

the quark model. Starting in 1967, this was accomplished to some degree in the electroweak theory, a theory that showed that at high energies two forces that are distinct at the energy levels normally experienced become a single force.

TOOLS The automation of manufacturing practices and machine tools was also facilitated by the development of chips and computers. By the 1950s milling machines, typesetting apparatuses, and other devices were being controlled by paper tape or by punch cards, but in the 1960s these controls were gradually replaced by electronic controls. The first industrial robots also appeared in the 1960s, although they did not become effective until after 1973 and were always more popular in Japan than in Western nations. Also by the mid-1960s, the electronic counterpart of the machine tool was invented. Known as CAD, computer-assisted design allows a tool designer to create an image of a part and make adjustments visually that otherwise would require hours of calculation. In some systems, the computer can then control a machine tool to produce the finished part.

By far the most influential new device of the period was the laser (light amplification by stimulated emission of radiation), an implement for producing coherent light of great intensity. Based on a concept first put forward by Einstein nearly 40 years earlier, the first breakthrough was not with light, but with microwaves. The maser, which uses the same principles as the laser, was most useful as a detector for faint microwaves, but a number of people quickly recognized that the maser could be adapted to produce electromagnetic waves as well as detect them. Such production was most available at low wavelengths of light and in the infrared. Within a half-dozen years of the maser, people were working on its light analog; by 1960 the first working lasers were developed, although ultimately the patent credit went to an ear-

lier inventor who actually had little impact on the field at its inception.

In the beginning, the laser was a wonderful toy for which the actual uses were uncertain. Soon it found applications in cutting and welding at all levels from eye surgery to machining parts. Farmers even used lasers to make sure fields were level. For the laser, an important transition came when lasers based on carbon dioxide were introduced in 1970. These were the first really powerful lasers. Like many developments during this period, however, the greatest applications were to come in the years after 1973.

Other devices of the period included those that allowed a number of new ways of observation, ranging from the traditional — the Hale reflecting telescope on Mt. Palomar, inaugurated right after World War II — to the unexpected — observations of individual atoms with the field ion microscope, something most scientists had thought would never be possible. Several new devices greatly improved observation of cells in biology, ranging from ways to see the insides of living cells to the scanning electron microscope that produces dramatic, three-dimensional-appearing views of surfaces.

TRANSPORTATION Both military and civilian air transportation underwent a profound change during World War II. Airliners inherited the powerful piston engines developed for heavy bombers, resulting in a series of four-engined planes that could cross the Atlantic Ocean in less than 20 hours. Jet engines, developed during the war, were installed on military planes in the late 1940s and civilian planes in the 1950s, reducing the Atlantic crossing to about seven hours. In most industrialized countries airlines underwent a similar development to that of railways during the 1840s and 1850s. Seating capacity reached 500 in large commercial craft termed jumbo jets; airport

facilities also were expanded. Flying became much cheaper and airlines became serious competition for railways, especially in the United States, and to a lesser degree in Europe. Because jet engines can develop much more thrust than can be achieved with propellers, weight became less of a problem and large jet planes became increasingly used for freight, such as perishable foods.

The jet engine was not the only new source of transportation power. The use of nuclear energy to power submarines was soon recognized as a great advantage because it would allow submarines to operate for extended periods without the need for refueling or resurfacing. The first nuclear submarine, the *Nutilus*, was commissioned in 1954. Nuclear submarines equipped with nuclear missiles became during subsequent years an important element in the arms race since they were mobile launching platforms whose location could not be detected by an enemy.

A few civilian ships powered by

nuclear reactors were built during this period. The first was the icebreaker *Lenin*, built by the Soviet Union; it started operating in the Arctic seas in 1959. The *Savannah*, launched by the United States, the *Mutsu*, launched by Japan, and the *Otto Hahn*, launched by Germany, all proved to be not economically viable. The construction of such ships has since been abandoned.

Work toward a nuclear airplane started in the United States in 1948, but was abandoned in 1961 after millions of dollars had been spent on the project. The biggest obstacle was that no airplane could afford to lift the heavy nuclear shield needed to protect the pilots against radiation from the reactor. Ideas for a nuclear rocket engine were also abandoned because of the nuclear pollution of the atmosphere such an engine would produce.

During the postwar years, both the Soviet Union and the United States continued developing rockets that were based on the German V-2 design. The aim of rocket development was initially

military — strategic medium-range missiles appeared in the Soviet Union around 1955 and in the United States around 1958. The deployment of intercontinental missiles followed in 1959. The launch of the first artificial satellite, *Sputnik*, in 1957 by the Soviet Union started “the race in space” between the United States and the Soviet Union. Progress was spectacular: The first astronauts circled Earth in the early 1960s, and humans landed on the Moon in 1969, less than 12 years after the launch of the first artificial satellites. The first inhabited space station, *Salyut 1*, was launched in 1971 by the Soviet Union.

Space technology has had a number of direct benefits for people around the world. Communications satellites have helped make Earth a “global village.” Weather satellites have given us the almost credible five-day forecast and have informed scientists about changes in the atmosphere. Resources satellites detect changes in forests and crops and locate mineral deposits.

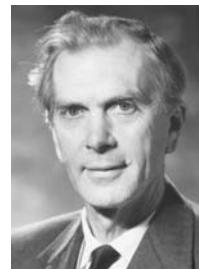
CHRONICLE

1946

► Anthropology

Robert Broom publishes a monograph on his finds of fossils of australopithecines in South Africa that begins to convince other anthropologists that these early hominids exist and are related to humans. See also 1938 ANTH.

Ruth Benedict's *The Chrysanthemum and the Sword*, financed by the U.S. government during World War II, is an effort to explain the Japanese culture to the West. See also 1934 ANTH.



(Sir) Martin Ryle

[b. Brighton, England, September 27, 1918, d. Cambridge, England, October 14, 1984]

Radio astronomy was still a brand new science in 1946 when Ryle began surveying the radio universe. By 1959 he had prepared a catalog of some 500 radio sources, which he expanded to about 5000 sources by 1965. He was a pioneer in using two radio telescopes and interferometry to improve resolution. From 1972 through 1974 he was also England's Astronomer Royal.

★ Astronomy

Several radio sources, including the one that will become famous as Cygnus A, are located to within a narrow region of the sky by James Hey, S.J. Parsons, and J.W. Phillips. See also 1942 AST; 1952 AST.

Martin Ryle uses two simple antennas together to improve the resolution of radio signals from space, the very beginning of interferometry for radio telescopes. See also 1887 AST; 1955 AST.

Work at Jodrell Bank center for radio telescope in England

begins on October 10 with observing the radar reflections from the Giacobinid meteor trails. See also 1932 AST; 1947 AST.

► Biology

Edward Lawrie Tatum [b. Boulder, Colorado, December

14, 1909, d. New York City, November 5, 1975] and Joshua Lederberg discover genetic recombination, a type of sexual exchange of genetic material, in the bacterium *Escherichia coli*. Independently Max Delbrück [b. Berlin, September 4, 1906, d. Pasadena, California, 1981] and Alfred Day Hershey [b. Owosso, Michigan, December 4, 1908, d. Syosset, New York, May 22, 1997] discover genetic recombination in bacteriophages (viruses that infect bacteria). In this process, genetic material from different viruses can be combined to form a new type of virus. *See also* 1945 BIO; 1969 BIO.

Ulf von Euler discovers the neurotransmitter noradrenaline. *See also* 1942 BIO; 1970 BIO.

Hermann J. Muller of the United States wins the Nobel Prize for physiology or medicine for his discovery of X-ray mutation of genes. *See also* 1926 BIO.

Chemistry

Linus Pauling suggests that enzymes work by lowering the energy barrier of a reaction through binding to a transitional state as the atoms in a compound move from position to position about their central core; his view is later established for many enzymes. *See also* 1938 BIO; 1969 BIO.

Robert Robinson determines the structure of strychnine. *See also* 1925 CHEM; 1947 CHEM.

James Batcheller Sumner, John Howard Northrop, and Wendell Stanley of the United States share the Nobel Prize in chemistry, Sumner for the first crystallization of an enzyme,



Joshua Lederberg

[b. Montclair, New Jersey, May 23, 1925]

In 1946 Lederberg and Edward Tatum announced that they had discovered genetic recombination in bacteria. Several years later Lederberg discovered that viruses called bacteriophages could transfer genetic material from one bacterium to another, a phenomenon he called transduction.

Northrop for his crystallization of enzymes, and Stanley for the crystallization of a virus. *See also* 1926 CHEM; 1929 CHEM; 1935 BIO.

Communication

Maurice V. Wilkes [b. Dudley, England, June 26, 1913] develops an early version of Assembler, a mnemotechnic language that simplifies considerably the programming of computers. *See also* 1949 COMM.

Albert Rose [b. New York City, March 30, 1910, d. July 26, 1990], Paul K. Weimer [b. Wabash, Indiana, November 5, 1914] and Harold B. Law [b. 1911, d. 1984] develop the image orthicon, an improved version of the orthicon. The image orthicon will become widely used by television companies because of its excellent sensitivity to low light levels. *See also* 1939 COMM.

The first mobile telephones are introduced.

The first zoom lens is introduced by Zoomar.

The word *bit*, derived from binary digit, to mean a single unit of information is suggested by John Wilder Tukey [b. Bedford, Massachusetts, 1915,

d. New Brunswick, New Jersey, July 26, 2000]. *See also* 1958 COMP.

Computers

On February 14 John Mauchly and John Presper Eckert demonstrate ENIAC, the first all-purpose, all-electronic computer, to scientists and industrialists. ENIAC, developed secretly during World War II, does not use binary numerals, however, but has its vacuum tubes arranged to display decimal numerals. Its early press releases claim such feats as multiplying 360 ten-digit numbers or extracting a square root "in a single second," but it draws so much electricity that it causes the lights in a nearby town to dim each time it is used. *See also* 1945 COMP; 1949 COMP.

The First Draft by John von Neumann of 1945, with co-authors Herman Goldstine and Arthur Burks, becomes the *Preliminary Discussion of the Logical Design of an Electronic Computing Instrument*, remaining unpublished but still extremely influential. *See also* 1945 COMP.

Earth science

Vincent Joseph Schaefer [b. Schenectady, New York, July 4,

1906, d. July 25, 1993] discovers in July by accident that frozen carbon dioxide causes supercooled water vapor to turn into snow. On November 13 he conducts a large-scale experiment by dropping dry ice into a cloud from an airplane, causing the first artificial snowstorm. On November 14 Bernard Vonnegut [b. Indianapolis, Indiana, August 29, 1914, d. Albany, New York, April 25, 1997] discovers that silver iodide can be used to produce precipitation when seeded into clouds — the actual experiment takes place in his laboratory using supercooled water. Silver iodide will become the main chemical used in cloud seeding.

Ecology & the environment

The International Whaling Convention is signed by the principal whaling nations, leading to the formation of the International Whaling Commission.

Energy

On December 24 the first Soviet nuclear reactor goes into operation under the direction of Igor Vasilevich Kurchatov [b. Sim, Russia, January 12, 1903, d. 1960]. *See also* 1942 ENER.

* Physics

John Blewett [b. Toronto, Ontario, April 12, 1910, d. Chapel Hill, North Carolina, April 7, 2000] reads a short letter in *Physical Review* by Russian physicists Dmitri Ivanenko and Isaak Pomeranchuk, which states their theory that large particle accelerators release electromagnetic radiation caused by the acceleration of electrons or other particles traveling in curved paths. Blewett demonstrates that this radiation, now known as synchrotron radiation, actually exists. At first viewed as a serious problem or at best a nuisance, by the 1980s synchrotron radiation will become desirable for many applications, and accelerators will be built in the 1990s solely for the purpose of producing such radiation for medical and manufacturing uses. *See also* 1943 TOOL; 1947 PHY.

Abraham Pais [b. Amsterdam, Netherlands, 1919, d. August 4, 2000] and C. Móller introduce the term *lepton* to describe lightweight particles not affected by the strong force. Today six leptons are recognized, the electron, muon, and tauon along with their associated neutrinos.

Marcello Conversi, Ettore Pancini, and Oreste Piccioni demonstrate that the meson known at this time, which has been found in cosmic rays, interacts too weakly with protons and neutrons to be the meson predicted by Hideki Yukawa in 1935. Robert Eugene Marshak [b. Bronx, New York, October 11, 1916, d. Cancun, Mexico, December 23, 1992] and Hans Bethe, independently of Shoichi

Sakata and Takeshi Inoue, rediscover the two-meson theory, which is that some unknown meson must be the Yukawa particle. *See also* 1942 PHY; 1947 PHY.

Percy Bridgman of the United States wins the Nobel Prize for physics for his discovery of the laws of high-pressure physics. *See also* 1905 MATR.

I Tools

The first synchrocyclotron is built at Berkeley. By November it produces alpha particles with an energy of 380,000,000 electron volts (MeV). *See also* 1946 PHY; 1949 MED.

► Transportation

The innovative Tucker Torpedo automobile, with its engine in the rear and a third front headlight, is introduced by Preston Tucker [b. Capac, Michigan, September 21, 1903, d. January 7, 1957]; by 1947 the company has produced only 51 cars, and collapses.

1947

▲ Archaeology

Willard Libby introduces the radioactive carbon-14 method of dating ancient objects, a method of identifying the date at which any once-living organism had died based on

the amount of carbon-14 in the remains. *See also* 1960 CHEM.

Two shepherd boys discover the Dead Sea Scrolls, Jewish religious documents from around the time of Christ, in a cave near Khirbet Qumran.

* Astronomy

Lyman Spitzer, Jr. [b. Toledo, Ohio, June 26, 1914, d. Princeton, New Jersey, March 31, 1997] speculates that astronomers might put telescopes of various kinds in orbit around Earth on artificial satellites to improve viewing and to observe at wavelengths blocked by the atmosphere. *See also* 1962 AST.

Alfred Charles Bernard Lovell [b. Oldland Common, England, August 31, 1913, knighted 1961] starts construction of a radio telescope with a fixed reflecting disk 66 m (218 ft) in diameter at the Jodrell Bank Experimental Station. The radio telescope will be the largest on Earth for many years. *See also* 1946 AST; 1967 AST.

❖ Biology

In *Sensory Mechanism of the Retina*, Finnish-Swedish physiologist Ragnar Arthur Granit [b. Helsinki, Finland, October 30, 1900, d. March 12, 1991] describes the results of his

studies since 1933, which show that retinal cones (which perceive color) and rods (which perceive low levels of light, but not color) work together in vision. *See also* 1967 BIO.

Czechoslovakian-American biochemists Carl Ferdinand Cori and Gerty Theresa Radnitz Cori and Bernardo Alberto Houssay [b. Buenos Aires, Argentina, April 10, 1887, d. Buenos Aires, September 21, 1971] of Argentina share the Nobel Prize for physiology and medicine, the Coris for their work on the metabolism of glycogen and Houssay for pituitary study. *See also* 1936 BIO; 1930 MED.

□ Chemistry

Alexander Todd synthesizes both adenosine diphosphate (ADP) and adenosine triphosphate (ATP), the compounds used by cells to handle energy. *See also* 1939 CHEM; 1951 BIO.

Ronald G.W. Norrish [b. Cambridge, England, November 9, 1897, d. Cambridge, June 7, 1978] and George Porter [b. Stainforth, England, December 6, 1920, d. August 31, 2002] develop flash photolysis, a method using very short bursts of intense light to photograph short-lived chemical reactions. *See also* 1967 CHEM.



Willard Frank Libby

[b. Grand Valley, Colorado, December 17, 1908, d. Los Angeles, September 8, 1980]

In 1947 Libby developed dating of artifacts based on carbon-14, a radioactive isotope created by sunlight acting on atmospheric nitrogen. The ratio of carbon-14 to stable carbon-12 is nearly constant in air and maintained by living organisms — plants incorporate carbon during photosynthesis and animals feed on plants or other animals. After death, however, no more atmospheric carbon is consumed, so reduction in carbon-14 (half-life 5730 years) can measure the time since death.



Dennis Gabor

[b. Budapest, June 5, 1900, d. London, February 9, 1979]

Gabor got his first patent at the age of 11 (for a carousel using real tethered airplanes). He studied electrical engineering in Germany, where he later developed the modern-day mercury-vapor lamp. After moving to England in 1933, he worked on electron microscope improvement, which led him in 1947 to conceive of a hologram, a method of using interference patterns in waves to record all information produced by an object reflecting or refracting the waves. His first holograms using mercury-vapor lamps demonstrated the principle, but were dim and difficult to view. Holograms require a coherent set of waves, not easily available until the advent of the laser in 1960. By 1964 holograms using lasers were producing three-dimensional images and since then many other applications of holograms have been developed.

Robert Sanderson Mulliken [b. Newburyport, Massachusetts, June 7, 1896, d. Arlington, Virginia, October 31, 1986] calculates the orbitals of electrons in molecules. *See also* 1966 CHEM.

Luis Federico Leloir [b. Paris, September 6, 1906, d. Buenos Aires, Argentina, December 2, 1987] begins research on the body's formation and breakdown of lactose, or milk sugar. He discovers that sugar nucleotides are the key elements involved in storing sugars and in conversion of sugars into energy. *See also* 1970 CHEM.

Sir Robert Robinson of England wins the Nobel Prize in chemistry for his study of plant alkaloids. *See also* 1946 CHEM.

Communication

Hungarian-British physicist Dennis Gabor develops the basic concept of holography, although the technique does not become truly practical until after the invention of the laser. *See also* 1955 COMM.

In February Edwin Land announces his invention of a camera and film system that develops pictures inside the camera in about a minute. The system is based on an invention made in 1928 by the German company Agfa, which

never commercializes the idea. The camera will go on sale on November 26, 1948, as the Polaroid Land Camera. *See also* 1928 COMM.

Chester Carlson sells his invention of xerography, a practical method of copying documents, to the Haloid Corporation (later renamed Xerox), although the process will not be fully developed until 1959. *See also* 1937 COMM; 1959 COMM.

Howard Aiken completes the Mark II computer at Harvard; its design is still almost entirely electromechanical, and it cannot compete with the electronic computers in existence. *See also* 1944 COMP; 1948 COMP.

Earth science

Measurements by the U.S. ship *Atlantis* establish that oceanic crust is much thinner than continental crust. *See also* 1961 EAR.

Sir Edward Victor Appleton of England wins the Nobel Prize for physics for his discovery of the ionic layer (ionosphere) in the atmosphere. *See also* 1939 EAR.

Electronics

On December 16 John Bardeen and Walter Houser Brattain [b. Amoy, China, February 10, 1902, d. Seattle, Washington, October 13, 1987], working at Bell Labs, perform the experiment that results in the first recognition of the transistor effect. They report this discovery to the management at Bell Labs on December 23. The transistor is announced to the general public in 1948. *See also* 1942 ELEC.

Energy

The two first nuclear reactors built by Canada in Chalk River, the ZEEP and the NRX, become operational. *See also* 1946 ENER; 1950 ENER.

Construction starts on the first U.S. peacetime nuclear reactor at Brookhaven, New York, on August 11. *See also* 1942 ENER; 1948 ENER.

Ralph Miller invents a version of the internal combustion engine in which the cycle of piston movements has a shorter compression stage than the expansion stage. The Miller-cycle engine provides higher power for its size and fuel consumption, but its complexity limits its use to motors for a few boats and electrical generators. *See also* 1877 ENER.

Andrei Sakharov [b. Moscow, May 21, 1921, d. Moscow, December 14, 1989] and Frederick Charles Frank [b. 1911, d. 1998] propose the use of muons to produce fusion reactions in a mixture of deuterium and hydrogen. This possibility will be rediscovered in 1957 by Luis Alvarez.

John Bardeen

[b. Madison, Wisconsin, May 23, 1908, d. January 30, 1991]

Few persons have won more than a single Nobel Prize and Bardeen is the only one so far to have won twice for physics — in 1956 for his contribution to the theory behind the transistor and in 1972 for helping to explain superconductivity. Bardeen recognized that in metals free electrons interact with the electrons bound into the metallic structure. This concept is not only part of the explanation of superconducting metals, but it helps explain many other interactions. Bardeen's insight was combined in 1957 with the concept of electrons pairing with holes developed by Leon Cooper and with calculations applying the ideas on a macroscopic scale by Bob Schrieffer to form the BCS theory of low-temperature superconducting.



From tubes to chips

While Thomas Alva Edison is remembered mainly as an inventor, he also made one extremely useful scientific discovery, now known as the Edison effect. He found that electricity flows through space from a heated metal. When the electron was discovered, the Edison effect was explained as electrons boiling off the metal, like water vapor from a heated tea kettle. Sir John Ambrose Fleming in 1904 developed the first practical application of the Edison effect. Electrons travel only to a positively charged anode. Since alternating current switches back and forth from negative to positive, the Edison effect can be used to turn alternating current into direct current. A device that does this is called a rectifier. Some electrical equipment, such as a radio receiver, will not work with alternating current, so rectification is needed when alternating current, which is more easily transported over long distances than direct current, is used as a power source.

The Edison effect is much more effective in a vacuum, so Fleming's device was enclosed in a partially evacuated glass tube. In America such a device is still called a tube (in England, it is a valve). Later inventors, notably Lee De Forest, found other ways to use the Edison effect in tubes. De Forest showed how to use tubes as amplifiers, for example.

De Forest's tubes greatly improved the radio, which had previously relied on crystals for rectification and earphones instead of amplification. It was not clear before De Forest's time why crystals could change alternating current to direct. When tubes came along, almost no one bothered to wonder why.

Tubes do not depend merely on the flow of electricity, as previous devices, such as electric motors, lights, or heaters, do; instead, they depend on control of the behavior of electrons. Therefore, we speak of devices that use tubes as electronic, not merely as electrical.

Tubes made possible such electronic devices as radio and television, but they had drawbacks: Heating a metal eventually causes it to boil away; the vacuum also tends to degrade. The power required for the Edison effect is fairly high; heat tends to build up in the vicinity of the tubes; and practical tubes have to be fairly large. While these problems were only a minor annoyance in building radio and television sets for the living room, they limited the size of portable sets. Also, when the first digital computers were built at the end of World War II, the many tubes needed

used enough power to cause lights to dim. In addition, the computers produced immense amounts of heat that had to be got rid of, they occupied large rooms, and they failed with such frequency that it was clear that larger computers could never be built.

Although almost no one wondered why crystals, which are semiconductors, work as rectifiers, scientists at Bell Laboratories decided in the late 1930s that it was worth looking into this question. One of them, William Shockley, wrote in 1939 in his lab notebook, "It has today occurred to me that an amplifier using semiconductors rather than vacuum tubes is in principle possible." Shockley found that some crystals worked better than others. The ones that worked best were impure crystals of germanium. By December 1948, Shockley, abetted by theoretical physicists John Bardeen and Walter Brattain, was able to modify the impurities to produce crystals that could also be used like a De Forest tube for amplification. The physicists called their new crystals transistors.

The transistor had none of the problems of the tube. It was small, needed no vacuum, did not wear out easily, and produced little heat. Soon transistor radios were the rage. The scientists won the 1956 Nobel Prize for physics. Large commercial computers, starting with Remington-Rand's UNIVAC, could be built.

What people did not fully realize — except for a few penetrating thinkers like Richard Feynman — was that the transistor was just the beginning. The transistor works because it is possible to adjust the impurities in a crystal so that one region has an excess of electrons while another has a deficit. Electrons will flow from one region to the other just as electrons cross the space between the cathode and anode in a tube. But there is no need for heat to be used; and since this is all happening at the molecular level, not a lot of space is required. A transistor can be made very small indeed. In fact, a transistor can easily occupy just a small region on a crystal. So you can put more than one transistor on each crystal.

And that is what scientists did. Beginning in the 1960s, ways were found to pack more and more transistors onto a given piece of crystal. Such a piece came to be called a chip. A chip is usually a fingernail-sized sliver of silicon "doped" with impurities in a pattern that enables it to serve as a computer memory or a central processing system or a controller of fuel injection in an automobile. The chip has made possible the incredible increase in power and availability of the personal computer. It has also invaded almost all aspects of daily life, controlling everything from your microwave oven to your car.

The U.S. Atomic Energy Commission is founded on January 1; its main responsibility is the development of nuclear arms. *See also* 1945 TOOL; 1952 TOOL.

II Food & agriculture

The first microwave cooker, the Radarange, goes on sale in the United States. It weighs 340 kg (750 lb), is 1.58 m (5 ft 6 in.) tall, and is intended for

restaurant use. *See also* 1945 FOOD.

❖ Materials

Robert K. Graham begins to market the first plastic lenses

for spectacles, which are made of a resin developed originally in World War II for lightweight fuel tanks and bomber windows. The resin is renamed Armolite by Graham.

Luis Walter Alvarez

[b. San Francisco, California, June 12, 1911, d. Berkeley, California, September 1, 1988]

Alvarez was a prolific inventor, working on both radar systems for navigation and the nuclear bomb during World War II, as well as the variable-focus lens for eyeglasses and the stabilizer used to keep hand-held cameras and binoculars steady. Although Alvarez contributed to experimental nuclear and particle physics in many ways, his 1968 Nobel Prize was for the discovery of various high-energy particle resonance states. He also aided his son Walter Alvarez in identifying the probable cause of the mass extinction some 65,000,000 years ago that eliminated the last dinosaurs along with many other species. His identification of iridium in a thin layer Walter Alvarez had found was the key to recognizing that the extinction was caused by an impact.

**♥ Medicine & health**

Chloramphenicol, a powerful antibiotic, is discovered. Its use is now restricted because of dangerous side effects. *See also* 1944 MED.

Cleveland surgeon Claude Schaeffer Beck [b. Shamoka, Pennsylvania, 1894, d. 1971] develops a way to alter an irregularly beating heart (arrhythmia) by opening the chest to expose the heart and applying an electric shock. *See also* 1956 MED.

*** Physics**

Cecil Frank Powell [b. Tonbridge, England, December 5, 1903, d. near Bellano, Italy, August 9, 1969] and coworkers discover the pi meson (later renamed the pion) on May 24 in cosmic rays. This particle is recognized as the meson Yukawa had predicted as the cause of the strong force. For the previous ten years, most physicists had believed that the mu meson, or muon, was the Yukawa meson, causing considerable confusion, although theoreticians in 1942 and 1946 independently concluded that there must be two different mesons. *See also* 1946 PHY; 1950 PHY.

Physicists working with the

General Electric Company's electron synchrotron particle accelerator observe large amounts of synchrotron radiation for the first time. This is electromagnetic radiation produced as moving charged particles change paths. At first an unwanted side effect, by the 1980s it will become a valued source of X rays. *See also* 1945 PHY; 1949 MED.

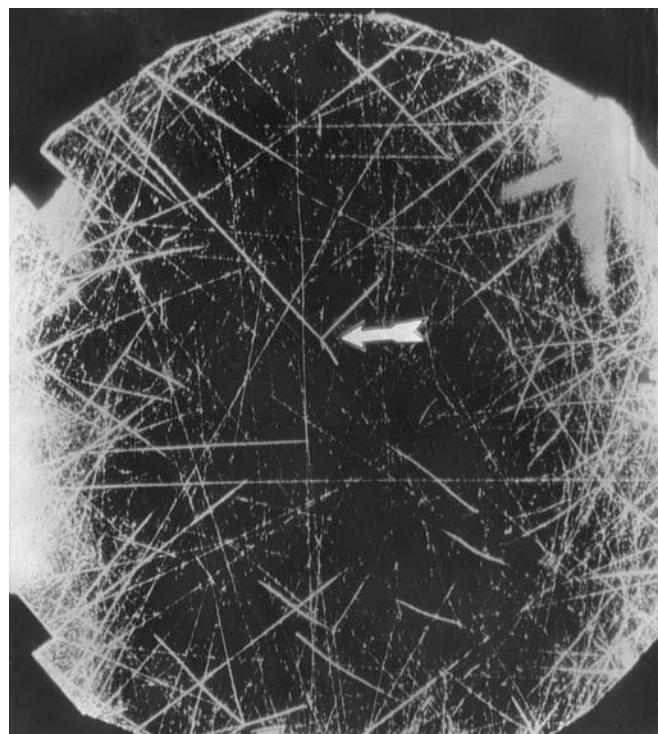
Willis Eugene Lamb, Jr. [b. Los Angeles, July 12, 1913] discovers that two states of the hydrogen atom, known as 2p and 2s for their electron positions, differ in energy levels, a shift that contradicts Erwin Schrödinger's wave equation. The discovery of the "Lamb shift" leads to the development of quantum electrodynamics (QED). A conference at Shelter Island, June 2-4, off Long Island, New York, includes reports on the Lamb shift, hyperfine anomalies, the two-meson hypothesis, and electron-neutron interaction. Physicists at the meeting and immediately following, starting with Hans Bethe on the train ride home, create quantum electrodynamics. *See also* 1948 PHY.

Luis Alvarez and Felix Bloch determine the magnetic moment of the neutron in liquids and solids. Previously

this had only been studied in beams of gases or beams of molecules. *See also* 1952 PHY.

George Rochester [b. Tyneside, England, February 4, 1908, d. Durham, England, January 10, 2002] and Clifford

Charles Butler [b. 1922, d. June 30, 1999] discover the first "V particle" in October while detecting cosmic rays in a cloud chamber. (This particular V particle will be later identified as the kaon, another meson.) *See also* 1948 PHY.



TRACK OF A COSMIC-RAY V PARTICLE The V particles were mysteries in 1947 and for several years thereafter. One ionizing particle suddenly decayed into two that headed away from each other, and the decay could not be explained by charge, parity, or mass conservation. Such particles always have to appear as pairs, we now know, because they need to conserve a then unknown property called strangeness.

I Tools

Charles Oatley [b. Frome, Somerset, England, 1904, d. March 11, 1996], building on the work of Manfred von Ardenne, much of which had been lost during World War II, develops what becomes the basic type of scanning electron microscope. *See also* 1938 TOOL; 1965 TOOL.

→ Transportation

The first airplane reaching supersonic speed in the United States, the Bell X-1, an experimental rocket plane, is flown by Charles E. (Chuck) Yeager [b. Myra, West Virginia, February 13, 1923]. Alice Chatham, a sculptor, designs the pressure mask and helmet worn by Yeager and other pilots using the X-1 rocket planes to make the first supersonic flights. *See also* 1944 TRAN; 1967 TRAN.

The first truly streamlined automobile, the Studebaker, designed by Raymond Loewy, is introduced in the United States. Although not a great success (people make jokes about not being able to tell the front from the rear), it influences all subsequent automobile design. *See also* 1934 TRAN; 1948 TRAN.

Hyman George Rickover [b. Makov, Russia (Poland), January 27, 1900, d. Arlington, Virginia, July 8, 1986] convinces the U.S. navy to begin a program of building nuclear submarines. *See also* 1942 ENER; 1955 ENER.

A C-54 transport plane from the U.S. air force crosses the Atlantic Ocean relying entirely on an automatic pilot. *See also* 1941 TRAN.

The tubeless tire is introduced by Goodyear in the United States. *See also* 1888 TRAN; 1953 TRAN.

1948

◀ Anthropology

Margaret Mead's *Male and Female: A Study of the Sexes in a Changing World* claims that many parts of Western culture are a result of child-rearing practices in the West. *See also* 1930 ANTH.

▲ Archaeology

A worker plowing a field in Norfolk, England, deeper than usual discovers a shiny gold-colored object that his supervisor dismisses as part of a brass bedstead. But as more pieces of metal appear, they are recognized as old and are taken to a local museum, which assembles them into pieces of a gold torc, a braided neck ornament from Celtic or early Roman times. After this, the plowmen watch for pieces of metal as they plow. *See also* 1950 ARCH.

★ Astronomy

George Gamow, Ralph Alpher [b. 1921], and Robert Herman [b. New York City, August 29, 1914, d. February 13, 1997] develop a theory of the origin of the universe in a giant explosion that starts the universe expanding. Their theory later will be labeled derisively the “big bang” theory by rival cosmologist Fred Hoyle, but the name sticks.

Gamow and his coworkers predict that the universe started hot in the initial explosion, creating high-energy radiation that now has cooled down to 5K (-268°C, or -450.4°F). This later will be found true in essence, if not quite accurate in terms of amount. *See also* 1927 AST; 1964 AST.

Herman Bondi [b. Vienna, Austria, November 1, 1919], Thomas Gold [b. Vienna, May 22, 1920], and Fred Hoyle [b. Bingley, England, June 24, 1915, d. Bournemouth, England, August 20, 2001]

advance the steady-state theory of the universe in which continual creation of matter powers expansion. Later this theory will lose most of its followers to the competing big bang theory. *See also* 1950 AST.

The 5-m (200-in.) telescope designed by George Ellery Hale, often referred to by the name of its site on Mt. Palomar in southern California, but later renamed the Hale telescope, becomes operational. J.A. Anderson gets the first look using the primary mirror in January, but the official dedication is on June 3. The Hale telescope will be the largest telescope of its time and remain the most effective for the next 40 years. *See also* 1936 AST; 1985 TOOL.



THE BULLET-NOSED STUDEBAKER Raymond Loewy's 1947 Studebakers were innovative in part because they were the first to have an overall design instead of individual hoods, trunks, roofs, and doors — but they were not popular (the 5-passenger Champion coupe looked backward to many potential buyers). Loewy tried a slightly different approach in 1950 with a new hood and fender design that resembled the front of a fighter airplane, which was termed bullet-nosed. But it was the longer, flatter rear that caught on and became almost the only style available for automobiles of the 1950s.



DEDICATION CEREMONY AT MT. PALOMAR OBSERVATORY The giant 200-in. (5-m) telescope at Mt. Palomar, later named for its designer George Ellery Hale, is dedicated on June 3, 1948, with nearly a thousand persons in attendance. The ceremony caps a 20-year process, from a Rockefeller Foundation grant in 1928 through site selection in the early 1930s, casting the mirror in the mid-1930s, grinding and polishing the mirror over a ten-year period (1937–47), and finally the installation in 1947. Even so, actual operation does not begin until 1949.

John Gateby Bolton [b. Sheffield, Yorkshire, England, June 5, 1922, d. Queensland, Australia, July 6, 1993] discovers three optical sources that are also radio sources. Two are outside the Milky Way, but the third is the Crab Nebula in our own galaxy. *See also* 1939 AST; 1953 AST.

Astronomers deduce from the infrared spectrum of the Moon's surface that it is covered by a layer of fine powder. *See also* 1870 AST; 1967 AST.

Biology

A group at Merck & Company headed by Karl August Folkers [b. Decatur, Illinois, September 1, 1906, d. December 9, 1997] discovers that certain bacteria require vitamin B₁₂ for growth, enabling them to use the bacteria as indicators so they can isolate the pure vitamin. *See also* 1912 BIO.

Chemistry

Paul J. Flory [b. Sterling, Illinois, June 19, 1910, d. Big Sur, California, September 9, 1985] recognizes that the size and shapes of the components of a polymer determine such features as possible chain length. *See also* 1974 CHEM.

Arne Tiselius of Sweden wins the Nobel Prize in chemistry for his research on serum proteins. *See also* 1930 CHEM.

Communication

The first cable television systems in the United States appear. *See also* 1923 COMM.

Hungarian-American physicist Peter Mark Goldmark in the United States develops the first long-playing record. *See also* 1984 COMM.

Ampex develops the first

audio recorder using magnetic tape. *See also* 1935 COMM; 1950 COMM.

Dennis Gabor publishes the first hologram in the May 15 issue of *Nature*. Inside a circle the hologram displays in black type the names of optics pioneers Huygens, Young, and Fresnel. *See also* 1947 COMM; 1971 COMM.

The magnetic drum for data storage in computers is introduced; it consists of a rapidly spinning drum covered with a magnetic film on which the data is encoded as tiny magnetic domains. The read-write heads (one or two electromagnets used to magnetize the domains, or "write," and to detect magnetic fields, or "read") move vertically to access the different tracks. *See also* 1944 COMM.

Cybernetics, or Control and Communication in the Man and the Machine by Norbert Wiener [b. Columbia, Missouri, November 26, 1894, d. Stockholm, Sweden, March 18, 1964] is an exhaustive mathematical analysis of the theory of feedback and automated processes. *See also* 1938 COMM; 1949 COMM.

Computers

IBM introduces the Selective Sequence Electronic Calculator (SSEC). Mainly electro-mechanical, it has electronic circuits for performing calculations and data storage. *See also* 1911 COMP; 1952 COMP.

Manchester University's Mark I prototype begins operating. Designed by Tom Kilburn [b. 1921, d. Urmston, England, January 17, 2001], it is a stored-program electronic computer. It is the first to use the von Neumann architecture. It stores

data in Williams tubes (a type of CRT tube). *See also* 1945 COMP; 1951 COMP.

Ecology & the environment

At least 20 people die and almost 6000 become ill in the steel town of Donora, Pennsylvania, as a smog of blast-furnace fumes and zinc-smelter emissions blankets the town for several days during a temperature inversion. *See also* 1952 ECOL.

Energy

A solar-heated house, designed by architect Eleanor Raymond [b. Cambridge, Massachusetts, March 23, 1887, d. 1989] and engineer Maria Telkes [b. Hungary, 1900, d. 1995] is built in Dover, Massachusetts. Employing flat-plate collectors, it is ultimately deemed a disappointment because of lack of heat storage on cloudy days. *See also* 1949 ENER.

Food & agriculture

Paul Müller of Switzerland wins the Nobel Prize for physiology or medicine for his discovery of the effect of DDT on insects. *See also* 1939 FOOD.

Materials

After a walk in the woods with his dog, Swiss engineer George de Mestral [b. June 19, 1907, d. February 8, 1990] steals an idea from the cockle-burs in his socks and the dog's coat and invents the fastener Velcro.

The Glidden Company introduces the first latex paint. Based on a form of synthetic rubber, it dries rapidly and can be cleaned or mixed with water instead of turpentine or

other hydrocarbons. *See also* 1875 MATR.

Medicine & health

John Franklin Enders [b. West Hartford, Connecticut, February 10 1897, d. Waterford, Connecticut, September 8, 1985], Thomas Huckle Weller [b. Ann Arbor, Michigan, June 15, 1915], and Frederick C. Robbins [b. Auburn, Alabama, August 25, 1916, d. August 4, 2003] learn how to grow mumps viruses in chick tissue using penicillin to prevent bacterial contamination; the same technique works for the polio virus. *See also* 1931 MED; 1954 BIO.

Elizabeth Hazen [b. Rich, Mississippi, August 24, 1885, d. Seattle, Washington, June 24, 1975] and Rachel Brown [b. Springfield, Massachusetts, November 23, 1898, d. January 14, 1980] discover the antibiotic Nystatin, which is the first safe fungicide. It has a wide field of applications, including treatment of athlete's foot and the restoration of books or paintings attacked by fungus. *See also* 1935 MED.

Sexual Behavior in the Human Male by Alfred Kinsey [b. Hoboken, New Jersey, June 23, 1894, d. Bloomington, Indiana, August 25, 1956] and colleagues is the first major study of sexual behavior. It reveals a surprisingly higher estimate of male homosexual behavior than most Americans had suspected. *See also* 1953 MED.

American optician Kevin Touhy develops the modern corneal contact lens when he accidentally breaks off the corneal part while making a lens of the older type. The older lens covered the white of

the eye as well as the cornea. *See also* 1887 MED; 1958 MED.

Swiss physiologist Walter Rudolf Hess [b. Frauenfeld, Switzerland, March 17, 1881, d. Locarno, Switzerland, August 12, 1973] describes in his book *Das Zwischenhim* ("the diencephalon") his technique of using small electrodes to stimulate specific regions of the brain and identify various regions in the brains of dog and cats. *See also* 1929 MED; 1949 MED.

A group led by Karl Folkers works out the structure of streptomycin.

* Physics

Richard Feynman, independently of Julian Seymour Schwinger [b. New York, New York, February 12, 1918, d. Los Angeles, July 16, 1994] and Shin'ichiro Tomonaga, develops renormalizable quantum electrodynamics (QED); Tomonaga was actually first, but his 1943 work was not known outside of Japan. *See also* 1947 PHY; 1965 PHY.

Freeman John Dyson, English-American physicist [b. Crowtherne, England, December 15, 1923] writes "The Radiation Theories of Tomonaga, Schwinger, and Feynman," in which he unifies

the three versions of quantum electrodynamics. Later Dyson will attempt to develop a new theory of gravitation and will become known for speculating about extraterrestrial civilizations.

German-American Maria Goeppert-Mayer [b. Katowice, Poland, June 28, 1906, d. San Diego, California, February 20, 1972] suggests that protons and neutrons in the atomic nucleus occupy shells similar to those occupied by electrons, an idea independently reached in 1949 by Johannes Hans Daniel Jensen [b. Hamburg, Germany, June 25, 1907, d. Heidelberg, West Germany, February 11, 1973]. *See also* 1913 PHY; 1963 PHY.

Seven months after the discovery of the first V particle, George Rochester and Clifford Butler find another. More will soon be observed. Such particles will not be understood until 1953, when the concept of strangeness will be introduced: V particles are strange particles. *See also* 1947 PHY; 1953 PHY.

Hendrik Casimir [b. The Hague, Netherlands, July 15, 1909, d. Heeze, Netherlands, May 4, 2000] proves theoretically that quantum fluctuations of an electromagnetic

field in a vacuum cause an attractive force between two sufficiently close parallel conducting plates; the plates need to be about a thousandth of a centimeter (0.0004 in.) apart. *See also* 1958 PHY.

In February Cesare Mansuetto Giulio Lattes [b. Curitiba, Brazil, July 11, 1924] and Eugene Gardner detect the first artificially produced pions (then called pi mesons) at a particle accelerator in Berkeley, California. *See also* 1947 PHY; 1962 PHY.

Using wave mechanics, John Hasbrouck Van Vleck [b. Middletown, Connecticut, March 13, 1899, d. Cambridge, Massachusetts, October 27, 1980] devises a theory that gives an accurate explanation of the magnetic properties of individual atoms in a series of chemical elements. *See also* 1977 PHY.

P. M. S. Blackett of England wins the Nobel Prize in physics for his discoveries with and improvements upon the Wilson cloud chamber. *See also* 1935 PHY.

I Tools

The first transfer machines for the manufacture of engine blocks start operation in Detroit. They perform 550 tooling operations in 15 min-

utes, accelerating the production of engines considerably. *See also* 1954 TRAN.

William Grey Walter, American-British neurologist [b. Kansas City, Missouri, February 19, 1910, d. May 6, 1977] develops the "tortoise," a precursor of modern robots. In this year and the next he builds Elmer and Elsie (both "Electro-Mechanical Robots, Light Sensitive") as part of his efforts to understand how the brain responds to the environment. Improved versions will be built in the next few years, with the results of the experiment to be described in *Scientific American* in 1950 and in a book in 1953. *See also* 1938 TOOL.

Paul Kirkpatrick [b. near Wessington, South Dakota, 1894, d. Palo Alto, California, December 26, 1992] and Albert Baez develop the X-ray reflection microscope for examination of living cells. This microscope will continue in use in medicine and also in astronomy, where it will be used to take X-ray photographs of individual galaxies. *See also* 1938 TOOL; 1957 TOOL.

→ Transportation

The U.S. Atomic Energy Commission starts work on the design of a nuclear plane. *See also* 1942 TRAN; 1956 TRAN.

Auguste Piccard builds his first bathyscaphe, a vessel designed for deep underwater exploration. *See also* 1930 EAR; 1960 EAR.

The General Motors Cadillac automobile introduces tail fins on its models in the United States, starting a trend toward using such fins as design elements that lasts throughout most of the 1950s. *See also* 1947 TRAN.



Richard Feynman

[b. Far Rockaway, New York, May 11, 1918, d. Los Angeles, California, February 15, 1988]

In 1947 Feynman was among several physicists whose combined work created quantum electrodynamics. One of his contributions, first published in 1948, is the Feynman diagram, a graphic way to calculate the results of particle interactions. Later Feynman developed a theory that protons and neutrons are made from smaller particles, although the quark theory of such particles is owed to Murray Gell-Mann. As a participant in the commission investigating why the space shuttle *Challenger* exploded, Feynman determined that cold weather had made a seal fail, allowing a jet of flame from the solid rocket booster to rupture the main fuel tank and set off a massive explosion.

The force of the vacuum

The existence of an actual vacuum was a subject for debate among scientists from Aristotle to those of the 20th century. Since light, magnetic fields, and heat all travel through a vacuum as waves, something must be there for the waves to move up and down or back and forth. Hence, no vacuum. Borrowing a word from Aristotle, scientists described various kinds of "aethers" that exist in even the hardest vacuum and that pervade space, providing a medium for waves. Maxwell's theory of electromagnetism reduced these different types to just one, called the ether. Various experiments were developed to detect this ether, of which the most famous was the Michelson-Morley experiment, which failed to find it. Finally, in 1905, Einstein banished the ether by means of special relativity and allowed the true vacuum to exist. Electromagnetic waves do not need a medium to move up and down since they are also particles that can travel through a vacuum like a bullet through the air.

But as particle physics developed, the "empty" vacuum once again became filled. The Heisenberg uncertainty principle of 1927 led particle physicists to predict that particles would arise spontaneously from the vacuum, so long as they disappear before violating the uncertainty principle. This view is correct. The quantum vacuum is a very active place, with all sorts of particles appearing and disappearing. In 1948 Hendrik Casimir predicted that the particle activity in a vacuum creates a force that pushes two parallel plates together if they are sufficiently close. Here

is why: Within the constrained space between the plates, fewer virtual particles can arise than outside of parallel plates, where there is more volume. Or think of the particles as waves: There is only room between the plates for short waves, which would have high energy. But the probability of high energy waves is small and they also vanish sooner than waves of lower energy. Outside the plates, there is room for longer wavelengths, which appear in greater numbers and persist for longer periods. The many outside the parallel plates push harder than the fewer inside.

Ten years after Casimir's theoretical study, careful experiments proved that such a force does occur in a vacuum. Surprisingly, it was not until 1996 that a physicist realized that the same effect occurs when two macroscopic objects are close to each other in a wavy medium, such as the ocean. Ships parked next to each other feel a force from the waves that tends to push them together.

Furthermore, starting in 1980 with the theory of the inflationary universe, particle physicists have told us that the entire universe was created as a "false vacuum," a quantum vacuum that has more energy in its nothingness than it should. The decay of that particular vacuum to an ordinary quantum vacuum produced all the mass in the universe and started the big bang. In this theory, which is not fully worked out, the particles that arise in the vacuum stay around long enough to create space.

Finally, there is the mysterious dark energy that seems to be pushing the universe apart. One idea is that dark energy is an effect of the virtual particles appearing and disappearing in the near vacuums between the galaxies.

1949

▲ Archaeology

A diver spots amphoras (Greek storage jars) on the sea bottom off the tiny island of Grand Congloué a few kilometers outside the harbor at Marseilles, France. In 1952 the site is determined to be the wrecks of two ships from classical times.

Mexican archaeologist Alberto Ruz Lhuillier [b. Paris, January 27, 1906, d. Montreal, Canada, August 25, 1979] excavates the previously untouched tomb of Pacal, eighth-century CE Maya ruler of Palenque. The tomb is filled with rich jade jewelry. The body wears a dramatic jade

burial mask, reminding archaeologists of that of Tutankhamen.

★ Astronomy

Fred Lawrence Whipple [b. Red Oak, Iowa, November 5, 1906] suggests (correctly) that comets are "dirty snowballs," consisting of ice or ammonia ice and rock dust. *See also* 1577 AST.

William Albert Hiltner [b. 1914, d. 1991] and John Scoville Hall [b. Old Lyme, Connecticut, June 20, 1908, d. October 15, 1991] discover polarization of light by interstellar matter. *See also* 1819 AST.

Ralph Belknap Baldwin [b. 1912] formulates his meteor

theory of the lunar surface. Before Baldwin, the most common explanation of the lunar craters had been volcanism. Baldwin demonstrates convincingly that the craters have been caused by impacts and not by volcanoes. *See also* 1921 AST.

◆ Biology

In *Die Polarisation des Himmelslichtes als orientierender Faktor bei den Tänzen der Bienen* ("the polarization of sky light as a means of orientation during the bee's dances"), Karl von Frisch shows that bees orient themselves during dances, which they use to communicate the location of food to other bees, by observing how sunlight is

polarized by reflection. *See also* 1950 BIO.

Belgian cytologist Christian René de Duve [b. Thames Ditton, England, October 2, 1917] discovers signs of a cellular structure that in 1955 he names the lysosome. *See also* 1945 BIO; 1974 BIO.

Kenneth Stewart Cole [b. Ithaca, New York, July 10, 1900, d. April 18, 1984] and George Marmont invent the "voltage clamp" for controlling the cell membrane potential. This will become the most important tool for investigating transmission of signals from nerves. The method is based on using the clamp to adjust the electric potential of a cell part, such as the axon of a

squid (used because of its large size), to a desired amount and then to use the same apparatus to change the potential. *See also* 1952 BIO.

Haldan Keffer Hartline [b. Bloomsburg, Pennsylvania, December 22, 1903, d. Fallston, Maryland, March 17, 1983] resumes his study of reactions in a single optic nerve fiber in the eye of the horseshoe crab, *Limulus*, focusing on intercellular recording from receptor units. *See also* 1967 BIO.

Donald Olding Hebb [b. Chester, Nova Scotia, 1904, d. 1985] writes *The Organization of Behavior*, which presents his cell-assembly theory that electrical activity in the brain underlies thoughts and other psychological events. He proposes that when synapses "fire" at the same time, they build closer connections, resulting in a neural network that contains memory. *See also* 1960 COMP.

Chemistry

Derek Harold Richard Barton [b. Gravesend, England, September 8, 1918, d. College Station, Texas, March 16, 1998] starts his work with complex organic molecules, such as steroids and terpenes, in which he demonstrates that shape is important to the properties of the molecule and even a small chemical change can often cause a major change in properties. *See also* 1969 CHEM.

English biochemist Dorothy Crowfoot Hodgkin [b. Cairo, Egypt, May 12, 1910, d. Shipston-on-Stour, England, July 30, 1994] is the first to use an electronic computer to work out the structure of an organic chemical, penicillin. *See also* 1950 EAR.

Glenn Seaborg and coworkers synthesize elements 98 and 97, californium (Cf) and berkelium (Bk).

Communication

The first modern photocomposition system, the Lumitype 200, is introduced by Photon in the United States. Commercialized in 1954, it can set between 30,000 and 50,000 characters per hour. *See also* 1894 COMM.

Claude Shannon publishes *The Mathematical Theory of Communication*, based on his dissertation from 1938. He argues that information is a measurable quantity and establishes the basic rules governing all kinds of communication, including electronic forms of communication. These results form the foundation of information theory, a general approach to all kinds of information handled electronically, including symbolic logic. *See also* 1938 COMM.

John Mauchly develops the Short Code, which allows computers to recognize mathematical codes consisting of two numbers; it is considered to be the first high-level programming language. *See also* 1946 COMM; 1954 COMM.

Computers

ORDVAC and ILLIAC I, computers using von Neumann architecture as outlined in unpublished works by John von Neumann of 1945 and 1946, are built by the U.S. army at its Aberdeen Proving Ground and by the University of Illinois in Champaign-Urbana, Illinois, respectively. *See also* 1946 COMP; 1953 COMP.

EDSAC (Electronic Delay Stor-

age Automatic Calculator) at Cambridge University goes into operation; one of the first stored-program computers to operate, it contains only 3000 vacuum tubes but is six times faster than previous machines. Data are stored in mercury delay lines. *See also* 1946 COMP.

John Mauchly and John Presper Eckert build the BINAC (Binary Automatic Computer). It is the first electronic stored-program computer in the United States, storing data on magnetic tape. BINAC goes into operation in August. *See also* 1946 COMP; 1951 COMP.

Energy

An experimental solar oven designed by engineer Felix Trombe [b. Nogent, France, 1906, d. Gautier, France, 1985] is built at Odeillo in the French Pyrenees. Using a paraboloid mirror to concentrate sunlight, it produces an output of 50 kW. *See also* 1948 ENER; 1954 ENER.

Materials

William Giauque of the United States wins the Nobel Prize in chemistry for his study in low-temperature chemistry. *See also* 1933 MATR.

Mathematics

André Weil proposes several conjectures about Riemann zeta functions (which are functions of a complex variable defined by the sum of an infinite number of complex fractions of the form $1/n^s$) in relation to finite algebraic fields. These conjectures strongly influence the fields of abstract algebra and algebraic topology for the next quarter of a century. *See also* 1974 MATH.

André Weil

[b. Paris, May 6, 1906, d. Princeton, New Jersey, August 6, 1998]

Weil was among the mathematicians who in 1939 began the Bourbaki series summarizing all known mathematics in a uniform symbolism. Early in World War II Weil, who was Jewish, escaped from occupied France and came to the United States (his sister, the philosopher Simone Weil, was a famous resistance fighter). He combined number theory with algebraic geometry in new ways, having a great influence not only on mathematics but also on particle physics.

Medicine & health

X rays from a synchrotron are used for the first time in medical diagnosis and treatment. *See also* 1946 TOOL.

Sir (Frank) Macfarlane Burnet [b. Traralgon, Australia, September 3, 1899, d. Melbourne, Australia, August 31, 1985] proposes that immune responses to foreign proteins develop as a person grows and are not inborn. *See also* 1898 BIO; 1960 MED.

James V. Neel [b. Hamilton, Ohio, March 22, 1915, d. Ann Arbor, Michigan, February 1, 2000] provides evidence that sickle cell anemia is an inherited disease. *See also* 1993 MED.

Australian psychiatrist John F. Cade describes the stabilizing effects of lithium, the first antidepressant. *See also* 1970 MED.

Philip Showalter Hench [b. Pittsburgh, Pennsylvania, February 28, 1896, d. Ocho Rios, Jamaica, March 30, 1965] and Edward Calvin Kendall [b. South Norwalk, Connecticut, March 8, 1886, d. Princeton, New Jersey, May 4, 1972]

announce that their experiments show that cortisone is effective in treating arthritis. *See also* 1936 BIO; 1950 MED.

Walter Hess of Switzerland and Egas Moniz (a.k.a. Antonio Moniz) of Portugal win the Nobel Prize for physiology or medicine, Hess for study of middle brain function and Moniz for prefrontal lobotomy. *See also* 1948 MED; 1935 MED.

❖ Physics

(Leo) James Rainwater [b. Council, Idaho, December 9, 1917, d. Yonkers, New York, May 31, 1986] begins to work on the idea that the nucleus of an atom might not be spherical, which he later will help to establish. *See also* 1939 PHY; 1975 PHY.

Hideki Yukawa of Japan wins the Nobel Prize for physics for his description of how the strong force holds protons and neutrons together in the atomic nucleus by exchanging medium-sized particles (later determined to be pions). *See also* 1935 PHY.

I Tools

The Soviet Union (Russia) in August explodes its first atomic bomb, using virtually all the plutonium it has on hand. U.S. plans for the bomb had been smuggled to the Soviet Union by such spies as Klaus Fuchs. *See also* 1945 TOOL; 1951 TOOL.

After a lab technician installs the accelerometers backward on the rocket sled of aerospace pioneer Major John Paul Stapp [b. Bahia, Brazil, July 11, 1910, d. Alamogordo, New Mexico, November 13, 1999], Captain Edward Aloysius Murphy pronounces: "If

there's more than one way to do a job and one of those ways will end in disaster, then someone will do it that way." Major (later Colonel) Stapp later abridges this to the more common form he terms "Murphy's law:" "If anything can go wrong, it will."

The first working atomic clock is built. *See also* 1967 COMM.

✈ Transportation

By adding a small rocket to the top of a captured German V-2 rocket, the first rocket with more than one stage is created. Launched from White Sands, New Mexico, by American scientists, it is able to reach a height of 400 km (240 mi), well beyond the atmosphere. *See also* 1944 TRAN.

A rocket testing ground is established at Cape Canaveral in Florida.

The Comet, the first jet airliner, designed by Geoffrey deHavilland [b. Surrey, England, July 27, 1882, d. London, May 21, 1965], makes its first flight on July 27. Comets will enter service in May 1952 but are withdrawn two years later after two crashes caused by material fatigue; they are returned to service in 1958, becoming the first passenger jets to cross the Atlantic Ocean. *See also* 1941 TRAN; 1968 TRAN.

1950

▀ Archaeology

A 40-acre field in eastern England at Ken Hill yields a Celtic hoard of Iron Age neck rings made of braided wire called torcs; the hoard includes the great gold Snettisham torc, considered one of Britain's

finest archaeological treasures. *See also* 1948 ARCH; 1990 ARCH.

★ Astronomy

Jan Hendrik Oort proposes that a great cloud of material orbiting the Sun far beyond the orbit of Pluto is the cause of long-period comets. Material from this "Oort cloud," as it will come to be known, from time to time is dislodged and falls toward the Sun, where we perceive it as a comet. *See also* 1951 AST.

Fred Hoyle coins the term "big bang theory" to explain the still new explanation of the origin of the universe advanced by George Gamow, Ralph Alpher, and Robert Herman. Hoyle prefers his own theory (with Herman Bondi and Thomas Gold), known as the steady state theory, so "big bang" is intended as a somewhat derisive nickname. *See also* 1948 AST.

❖ Biology

Maurice Hugh Frederick Wilkins [b. Pongaroa, New Zealand, December 15, 1916] begins working on X-ray diffraction studies of DNA. Alec Stokes [b. June 27, 1919, d. February 5, 2003], after seeing the first images, works out on the train on the way home from the laboratory that DNA probably has a helical structure. *See also* 1953 BIO.

Austrian-American biochemist Erwin Chargaff [b. Czernowitz, Austria, August 11, 1905, d. New York City, June 20, 2002] demonstrates that the number of adenine bases in DNA is equal to the number of thymine bases and the number of cytosine bases is equal to the number of guanine bases; this is an important clue to DNA's structure.

He observes that "as far as chemical possibilities go, they [the bases] could very well serve as one of the agents, or possibly as the agent, concerned with the transmission of inherited properties." *See also* 1944 BIO; 1953 BIO.

Barbara McClintock [b. Hartford, Connecticut, June 16, 1902, d. September 2, 1992] publishes her discovery of transposons — mobile genetic elements popularly called jumping genes — in maize. Her work will be ignored until the 1970s. *See also* 1983 BIO.

Karl von Frisch's *Die Sonne als Kompaß im Leben der Bienen* ("the Sun as compass in the life of bees") reports his research showing that bees keep track of their paths to sources of nectar and back to the hive by using the Sun to maintain true directions. *See also* 1949 BIO; 1973 ECOL.

□ Chemistry

Otto Diels and Kurt Alder of Germany win the Nobel Prize in chemistry for their synthesis of organic compounds of the diene group. *See also* 1928 CHEM.

☛ Communication

Paul Weimer, Stanley V. Forge, and Robert R. Goodrich develop the vidicon, a television camera tube. The principle of the tube is similar to that of the orthicon tube except that the image is formed on a photoconductive selenium target and that electrons from the target are discharged by photoconduction rather than photoemission. *See also* 1946 COMM.

▀ Computers

Alan Turing proposes in an article in the journal *Mind*,

"Can a Machine Think?" a test to determine if a computer has real intelligence. In the "Turing test," as it comes to be known, a computer in one room that can communicate with humans in another room must be able to convince the humans that it is intelligent. *See also* 1937 COMP; 1954 COMP.

Earth science

Hannes Alfvén shows that the interaction of the solar wind with the atmosphere causes auroras. *See also* 1939 EAR; 1970 EAR.

In April John von Neumann, working with a team of meteorologists and ENIAC — one of the first computers — makes the first computerized 24-hour weather predictions. *See also* 1869 EAR; 1951 AST.

Energy

The first nuclear reactor in England goes into operation at Windscale. Its primary purpose is to produce fuel for a nuclear bomb. *See also* 1947 ENER; 1953 ENER.

Food & agriculture

Archaeologist (Vere) Gordon Childe [b. Sydney, Australia, April 14, 1892, d. Mt. Victoria, Australia, October 19, 1957] renames the Agricultural Revolution the Neolithic Revolution to emphasize that the changes of that period (roughly 10,000 BP) involved more than just farming.

The artificial sweetener cyclamate is introduced. *See also* 1879 FOOD; 1965 FOOD.

Medicine & health

Robert Wallace Wilkins [b. Chattanooga, Tennessee, December 4, 1906] introduces

the treatment of high blood pressure with reserpine, following the practice of using the drug in the form of snake-root in India. *See also* 1952 MED.

Rosalyn Yalow [b. New York City, July 19, 1921] and Solomon A. Berson [b. New York City, April 22, 1918, d. Atlantic City, New Jersey, April 1972] begin a collaboration during which they invent radioimmunoassay, a test that uses radioactive isotopes to measure concentrations of biological compounds. *See also* 1977 MED.

Philip Hench and Edward Kendall of the United States and Tadeusz Reichstein of Switzerland win the Nobel Prize for physiology or medicine for the discovery of cortisone and other hormones of the adrenal cortex and their functions. *See also* 1949 BIO; 1936 BIO.

Physics

Pakistani-British physicist Abdus Salam [b. Jhang Maghiana (Pakistan), January 29, 1926, d. Oxford, England, November 21, 1996] proves that Hideki Yukawa's pion theory of nuclear forces is renormalizable — that is, forces can be computed without unwanted infinite results if those in one direction are balanced with their opposites. *See also* 1935 PHY.

Cecil Powell of England wins the Nobel Prize for physics for his photographic study of atomic nuclei. *See also* 1947 PHY.

Tools

German-French physicist Alfred Kastler [b. Guebwiller, France, May 3, 1902, d. Ban-

dol, France, January 7, 1984] develops optical pumping, a system of using light or radio waves to excite atoms, which then emit electromagnetic waves that can be studied to reveal the atomic structure. This is an important precursor to the laser. *See also* 1960 TOOL.

Transportation

The first automobile to use a gas turbine for power is introduced by Rolls-Royce in an experimental version. It attains speeds of 240 km (150 mi) per hour. *See also* 1963 TRAN.

1951

Astronomy

Dutch-American astronomer Dirk Brouwer [b. Rotterdam, Netherlands, September 1, 1902, d. New Haven, Connecticut, January 3, 1966] becomes the first astronomer to use a computer to calculate planetary orbits, using data collected since 1653 and predicting the orbits of the five outer planets through 2060. *See also* 1949 CHEM.

Harold Ewen [b. Chicopee, Massachusetts, March 7, 1922] and Edward Mills Purcell discover the 21 cm (8.3 in.) emission from interstellar hydrogen, thus confirming Hendrik Van de Hulst's prediction. It is the first observation of a radio frequency spectral line observed in space. This line is produced by a change in the spin states of low-temperature hydrogen atoms in outer space. *See also* 1944 AST.

Astronomer William Wilson Morgan [b. Bethesda, Tennessee, January 3, 1906, d. Williams Bay, Wisconsin, June

21, 1994] is the first astronomer to map the spiral structure of the Milky Way Galaxy using distances to stars, establishing that its structure is much like that of M31. He presents his map of the Milky Way to the American Astronomical Society at their December meeting. Jan Hendrik Oort, C. Alex Muller and Hendrik Van de Hulst also construct a map of the Milky Way Galaxy, using Doppler shifts observed in the 21-cm (8.3-in.) emission line of hydrogen. *See also* 1927 AST.

The Lyman-alpha line, a resonance line of hydrogen, caused as an electron falls from one orbital to another, is discovered in the solar spectrum using measurements made by instruments aboard from rockets.

Gerard Kuiper calculates that short-period comets begin in a group of objects (the Kuiper belt) that orbit the Sun just beyond the orbit of Neptune. *See also* 1950 AST.

Rudolph Leo B. Minkowski [b. Strassburg, Germany, May 28, 1895, d. Berkeley, California, January 4, 1976] and Walter Baade discover the first optical objects other than the Sun that can be related to known radio sources. *See also* 1952 AST.

Biology

Linus Pauling and Robert B. Corey determine that proteins tend to form into a structure called the alpha helix, a right-handed helix (three-dimensional spiral) formed by hydrogen bonding. *See also* 1953 BIO.

Albert Lester Lehninger [b. Bridgeport, Connecticut, February 17, 1917, d. March 4,

1986], working with Eugene Kennedy and, independently, several other biologists, including James Frederick Bonner [b. September 1, 1910, d. September 13, 1996], shows that mitochondria carry out oxidative phosphorylation, an important part of the Krebs cycle that is the main energy source for cells. *See also* 1857 BIO; 1955 BIO.

John Eccles [b. Melbourne, Australia, January 27, 1903, d. 1997] and coworkers succeed in inserting microelectrodes into nerve cells of the central nervous system and record the electrical responses produced by excitatory and inhibitory synapses. *See also* 1953 BIO.

Feodor Lynen [b. Munich, Germany, April 6, 1911, d. Munich, August 6, 1979] isolates coenzyme A from yeast and establishes that it is the first step in the formation of cholesterol and fatty acids. *See also* 1945 BIO; 1964 BIO.

The Origin, Variation, Immunity, and Breeding of Cultivated Plants by Russian Nikolay Vavilov [b. Moscow, November 25, 1887, d. Saratov, Russia, January 26, 1943], published eight years after his death, describes his work in finding the evolutionary basis of the immunity of various strains of wheat to disease and his efforts to breed improved varieties.

Chemistry

Robert Burns Woodward [b. Boston, Massachusetts, April 10, 1917] synthesizes the steroids cortisone and cholesterol. *See also* 1947 CHEM; 1965 CHEM.

Ernst Otto Fischer [b. München-Solln, Germany, November 10, 1918] begins his research into the structure

Rachel Carson

[b. Springdale, Pennsylvania, May 27, 1907, d. Silver Spring, Maryland, April 14, 1964]

In the 1950s Carson's articles and popular books about marine biology, notably *The Sea Around Us* in 1951, which won numerous prizes, made her familiar to readers interested in science or the sea. In the 1960s Carson's *Silent Spring* prompted worldwide interest in the environment and concern about the damage caused by chemical pesticides. Carson's book and publicity surrounding it led to the 1972 ban on DDT in the United States.



of the newly discovered ferrocene, eventually showing that it is a new type of metal-organic compound with an atom of iron sandwiched between two carbon rings. *See also* 1973 CHEM.

John Warcup Cornforth [b. Sydney, Australia, September 7, 1917] and coworkers complete the first synthesis of a nonaromatic steroid. *See also* 1975 CHEM.

Edwin McMillan and Glenn Seaborg of the United States win the Nobel Prize in chemistry for their discovery of plutonium and research on transuranium elements. *See also* 1941 CHEM.

Communication

Transcontinental television in the United States is inaugurated.

Fred Waller [b. Brooklyn, New York, March 10, 1886, d. May 18, 1954] introduces CinemaScope, the projection of films on a wide, curved screen by three projectors, which gives an effect of three-dimensions. This is the first of three types of motion picture systems with enhanced dimensionality introduced about this time; all are mainly intended to give movies a competitive advantage over television. *See also* 1900 COMM; 1952 COMM.

A video tape recorder using

magnetic tape is developed by Armour Research and demonstrated to Ampex, which starts its own research program. *See also* 1939 COMM; 1956 COMM.

Grace Hopper develops the first compiler, called A0, which translates the codes used by programmers into binary machine code. *See also* 1949 COMP; 1953 COMM.

Buffer memory, which temporarily stores data as it moves from or to slow peripherals, thus freeing the central processor for other tasks, is introduced by Remington.

Computers

In February Ferranti installs the Mark I, the first commercial computer. It is based on the Mark I computer developed by Tom Kilburn at Manchester University. *See also* 1948 COMP.

John Mauchly and John Presper Eckert build UNIVAC I, the first electronic computer to be commercially available in the United States and the first to store data on magnetic tape. It incorporates 100 mercury delay lines and 5000 vacuum tubes. In March the first UNIVAC I is installed at the U.S. Census Bureau. *See also* 1949 COMP; 1954 COMP.

The military supercomputer Atlas, named after a character

in the comic strip *Barnaby*, is equipped with magnetic drums with a capacity of 16,384 words of 24 bits each. It is a descendant of several secret special-purpose decoding machines that also used magnetic drum memories, the first made by winding magnetic tape around the drum (in 1947).

Ecology & the environment

Rachel Carson's *The Sea Around Us* is a popular book describing the oceans.

Electronics

William Shockley, Stanley Morgan, Morgan Sparks, and Gordon Teal [b. Dallas, Texas, January 10, 1907, d. Dallas, Texas, January 7, 2003] develop the p-n junction transistor using crystal growth techniques. *See also* 1947 ELEC; 1954 ELEC.

Western Electric starts the commercial production of transistors. *See also* 1947 ELEC; 1952 ELEC.

Energy

Canadian-American physicist Walter Henry Zinn [b. Kitchener, Ontario, December 10, 1906, d. February 14, 2000] develops an experimental breeder reactor that is built at Arco, Idaho. On December 20 the nuclear reactor, known as

Experimental Breeder Reactor 1 (EBR-1), starts operation at the U.S. Atomic Energy Commission's laboratories, producing the world's first usable amount of electric power from nuclear energy. A breeder reactor produces more plutonium than the uranium it burns for fuel. Contemporary accounts claim it is like getting two pounds of coal for each one burned and proclaim the new reactor the start of an era of cheap energy. *See also* 1950 ENER; 1955 ENER.

Food & agriculture

Embryos are transplanted in cattle for the first time. *See also* 1901 FOOD; 1973 FOOD.

Materials

Fred Joyner of Eastman Kodak, measuring the speed of light through plastics for an aircraft-cockpit project, finds that the 910th compound he measures sticks the lenses of the refractometer together so tightly that they cannot be unstuck. When a panicked Joyner takes the problem caused by the cyanoacrylate compound to his supervisor, Harry Coover [b. Newark, Delaware, March 6, 1919], Coover remembers he had to give up his own World War II experiments with cyanoacrylates because the chemicals stuck to everything they touched. Coover decides that he and Joyner might have found a new kind of glue; indeed, they had discovered the first superglue, although it will take seven years more before the superglue will be introduced commercially.

Mathematics

Economist Kenneth Arrow [b. New York City, August 23, 1921]

proves that when there are three or more candidates no method of electing a winner guarantees that the most popular candidate will win the election.

Medicine & health

U.S. surgeon John Gibbon develops the heart-lung machine. *See also* 1935 MED; 1953 MED.

Austrian-American Carl Djerassi [b. Vienna, October 29, 1923] synthesizes norethindrone, the steroid oral contraceptive now known as the birth-control pill. *See also* 2000 BCE MED; 1956 MED.

Antabuse, a drug that prevents alcoholics from drinking, is introduced.

William Sweet [b. 1910, d. Brookline, Massachusetts, January 22, 2001] at Massachusetts General Hospital and Frank Wrenn at Duke use positron-emitting radionuclides for medical applications. *See also* 1974 MED.

Max Theiler of South Africa wins the Nobel Prize for physiology or medicine for developing the 17-D yellow fever vaccine. *See also* 1937 MED.

Physics

Aage Niels Bohr [b. Copenhagen, Denmark, June 19, 1922] and Ben Roy Mottelson [b. Chicago, Illinois, July 9, 1926] work out the mathematical details of a theory of the atomic nucleus originally developed by James Rainwater. They show that the nucleus is not necessarily spherical and provide details useful in nuclear fusion. *See also* 1949 PHY; 1952 TOOL.

Tools

Erwin Wilhelm Mueller [b.

Berlin, June 13, 1911, d. Washington, DC, May 17, 1998] develops the field ion microscope. *See also* 1955 TOOL.

The Soviet Union (Russia) develops the first atomic (nuclear fission) bomb of its own design; a previously tested atomic weapon had been based on stolen U.S. plans. *See also* 1949 TOOL.

Sir John Cockcroft of England and Ernest Walton win the Nobel Prize in physics for discovery of the transmutation of atomic nuclei in accelerated particles. *See also* 1932 TOOL.

1952

Archaeology

Michael Ventris [b. Wheathampstead, England, July 12, 1922, d. Hatfield, England, September 6, 1956] deciphers linear B, one of the forms of writing used by the Minoans of Crete. Although archaeologists had been expecting to find a previously unknown Cretan language, linear B encodes a known form of ancient Greek.

Russian linguist Yuri Knorosov demonstrates that Maya writing is a phonetic and syllabic hieroglyphic script, based on principles similar to those of Egyptian hieroglyphs.

Jacques-Yves Cousteau and Fernand Benoit [b. 1891, d. 1969] direct the first investigation of an ancient wreck using scuba apparatus. *See also* 1943 TRAN; 1985 TRAN.

Oscar T. Broneer [b. Backebo, Sweden, 1895(?), d. Corinth, Greece, February 22, 1992] discovers the site of the Temple of Poseidon, fourth-century BCE Corinthian shrine that,

along with Olympia, Delphi, and Nemea, was one of the main temples at which all Greeks of Antiquity worshiped. The Temple of Poseidon was famed as the site of the Isthmian games, second only to the Olympics.

The first examples of the distinctive pottery produced by the ancestors of the Polynesians, called Lapita after the site, are found on New Caledonia, an island in Melanesia.

Astronomy

Martin Ryle identifies the radio source Cygnus A, the first radio galaxy to be definitely identified with a single source. Originally, Cygnus A was thought to be two galaxies in collision, but later research shows that it is a giant elliptical galaxy bisected by a dust lane. The dust may have occurred from absorption of a smaller spiral galaxy into the main elliptical one. *See also* 1946 AST.

There is a burst of knowledge concerning star formation. Adriaan Blaauw [b. April 12, 1914] shows that the expansion of zeta-Persei cluster started 1,300,000 years ago, proving that stars are continuously created in the Milky Way Galaxy. George H. Herbig [b. January 2, 1920] reports his observation of Herbig-Haro objects (regions where stars are formed). Paul Willard Merrill [b. August 15, 1888, d. July 19, 1961] discovers the element technetium in S-type supergiants. Technetium has a short half-life, showing that these stars have been formed recently. Martin Schwarzschild [b. Potsdam, Germany, May 31, 1912, d. Princeton, New Jersey, April 10, 1997] analyzes the evolution of stars by

studying spectrum-luminosity graphs of stars in globular clusters. *See also* 1945 AST.

Walter Baade announces an error in the Cepheid luminosity scale, based on his discovery that Cepheid variables in population I stars have different absolute magnitudes than Cepheid variables belonging to population II. The new magnitudes imply that galaxies are about twice as remote as had been previously thought. *See also* 1929 AST.

Biology

Alfred Hershey and Martha Chase [b. Cleveland Heights, Ohio, 1930, d. Lorain, Ohio, August 8, 2003] perform the “blender experiment,” proving that DNA is the genetic material by separating DNA from the protein coats of viruses and showing that DNA alone passes along the characteristics of the virus. *See also* 1946 BIO; 1969 BIO.

William Hayes [b. County Dublin, Ireland, 1918, d. Sydney, Australia, 1944] discovers that even a very small part of the bacteria *Escherichia coli* can transmit heritable characteristics independently from cell division and reproduction — in this case, a gene for streptomycin resistance. About the same time Joshua Lederberg discovers that viruses that attack bacteria can transmit genetic material from one bacterium to another, one of the significant steps leading toward genetic engineering. Lederberg introduces the term *plasmid* to describe the bacterial structures he has discovered that contain extra-chromosomal genetic material. *See also* 1928 BIO; 1959 BIO.

Alan Lloyd Hodgkin [b. Ban-

bury, England, February 5, 1914, d. Cambridge, England, December 20, 1998] and Andrew Fielding Huxley [b. London, November 22, 1917] experiment with microelectrodes in the axon of the squid, which has a nerve with an unusually large axon, the long extension of a nerve. Based on this research, they formulate the modern theory of excitation of nerves: As a nerve impulse passes, sodium ions flood the cell and potassium ions are pumped out. *See also* 1949 BIO; 1963 BIO.

Rita Levi-Montalcini [b. Turin, Italy, April 22, 1909] discovers the first growth factor, a protein in vertebrates that stimulates cell division and growth. *See also* 1956 BIO.

Bernard Katz [b. Leipzig, Germany, March 26, 1911, d. April 23, 2003] discovers that the neurotransmitter acetylcholine is released from nerve endings in small packets, or quanta, with each packet becoming a very brief signal for action to the target muscle fiber. *See also* 1970 BIO.

Robert Briggs [b. 1911, d. 1982] and a colleague clone tadpoles using embryo nuclei of leopard frogs. *See also* 1938 BIO; 1962 BIO.

A calf is produced using frozen semen.

Alan Turing suggests that interactions between the strengths of various chemicals, which he calls *morphogens*, determine the biological makeup of a given species or an individual; a later example of this idea is that two morphogens determine the stripes on a zebra or the spots on a leopard. *See also* 1950 COMP.

Chemistry

Geoffrey Wilkinson [b. Toddington, Yorkshire, England, July 14, 1921, d. London, September 26, 1996] and R. B. Woodward write “The Structure of Iron Biscyclopentadienyl,” about the structure of an organic compound of iron. The paper becomes one of the founding documents of organometallic chemistry. *See also* 1951 CHEM; 1973 CHEM.

Kenichi Fukui [b. Nara, Japan, October 4, 1918, d. Kyoto, Japan, January 9, 1998] is able to correlate the chemical reactivity in aromatic hydrocarbons to the orbitals of electrons in their molecules; two years later he will supply the theoretical background for this based on quantum mechanics. *See also* 1981 CHEM.

Albert Ghiorso [b. 1915] and coworkers discover einsteinium (Es), the artificial element with an atomic number of 99, and fermium (Fm), element number 100, in the debris of the first thermonuclear explosion.

Archer Martin of England and Richard Synge win the Nobel Prize in chemistry for their separation of elements by paper chromatography. *See also* 1938 CHEM.

Communication

Truly three-dimensional-appearing motion pictures are shown in the United States in a system called Natural Vision, although viewers must wear special polarizing glasses; the first film is *Bwana Devil*. *See also* 1893 COMM.

Cinemascope wide-screen movies are introduced commercially. It is the last of the partial 3D systems of 1951–52 and the only one to have,

along with its imitators, a lasting effect on how films are made. Images are compressed laterally by an anamorphic lens during filming and decompressed during projection onto a wide screen. *See also* 1925 COMM; 1951 COMM.

UHF (ultra-high frequency) television broadcasting is authorized in the United States. *See also* 1941 COMM.

Computers

John von Neumann's IAS computer is completed at the Institute of Advanced Studies in Princeton; it is based on von Neumann architecture and has parallel-processing capabilities. *See also* 1949 COMP.

On April 29 IBM announces the 701, also called the Defense Calculator. It is a 36-bit computer of the von Neumann type, developed by Bob Overton Evans [b. August 19, 1927] and coworkers. It is equipped with an electrostatic memory of 20,480 digits and uses either 18-bit or 36-bit words; a total of 19 IBM 701 computers are built. *See also* 1949 COMP; 1953 COMP.

The CBS television network uses a UNIVAC computer to predict the results of the U.S. presidential election. UNIVAC's first prediction of a landslide victory for Dwight D. Eisenhower is right on the mark but not believed by its operators. They quickly reprogram it so that it incorrectly predicts a close contest. *See also* 1951 COMP.

Earth science

James Van Allen develops the rockoon, a rocket launched from a balloon, to study the physics of the upper atmosphere.



James Alfred Van Allen

[b. Mount Pleasant, Iowa, September 7, 1914]

During World War II Van Allen helped develop the radio proximity fuse for rocket-propelled bombs and antiaircraft weapons. He continued to work with rockets after the war, becoming famous for his use of a Geiger counter on the first successful U.S. Earth-orbiting satellite, which detected the powerful belts of radiation that have been named after him. After the initial discovery, Van Allen mapped the two main Van Allen radiation belts, which are regions of charged particles trapped by Earth's magnetic fields.

❖ Ecology & the environment

A long-lasting temperature inversion traps coal smoke along with fog for five days in London, England, forming a smog that takes 4000 lives, mostly the elderly and infirm. *See also* 1948 ECOL; 1963 ECOL.

Arie Haagen-Smit [b. Utrecht, Netherlands, December 22, 1900, d. March 18, 1977] reports that one type of smog is a product of a photochemical reaction between hydrocarbons and nitrogen oxides.

▀ Electronics

The first hearing aids equipped with junction transistors appear on the market. Bell, because of its commitment to helping the deaf since Alexander Bell, waives all patent royalties on the application of the transistor in hearing aids. *See also* 1951 ELEC; 1964 ELEC.

☒ Energy

The first accident at a nuclear reactor occurs at Chalk River in Canada, where a technician's error causes a hydrogen explosion in the nuclear core. There are no casualties. *See also* 1947 ENER; 1955 ENER.

☒ Food & agriculture

P.W. Brian and other scientists in Europe and the United States find that among the

gibberellins in soil fungi, the active growth hormone is one that is named gibberellic acid. *See also* 1939 FOOD.

❖ Materials

(William) Conyers Herring [b. Scotia, New York, November 15, 1914] and John K. Galt [b. Portland, Oregon, September 1, 1920] demonstrate that thin "whisker" crystals of tin are much stronger than tin in bulk is. *See also* 1938 MATR.

Alistair Pilkington [b. 1920, d. 1995] introduces the "floating glass" method for the continuous production of glass sheet; the glass floats on liquid tin on which it is stretched before being cooled down.

Σ Mathematics

Andrew Gleason, Deane Montgomery [b. Weaver, Minnesota, 1909, d. Chapel Hill, North Carolina, March 15, 1992], and Leo Zippin solve number five from David's Hilbert's list of 23 unsolved problems. Hilbert's fifth problem as originally formulated asked under what conditions one had to assume differentiability for functions defining a continuous transformation group. By the time Gleason, Montgomery, and Zippin solve the problem, it has been redefined in terms of all locally bicompact groups. *See also* 1900 MATH.

♥ Medicine & health

French psychiatrists Jean Delay [b. 1907, d. 1987] and Pierre Deniker [b. 1917, d. 1998] synthesize chlorpromazine (Thorazine), usually considered the first tranquilizer. About the same time Robert Wilkins discovers that reserpine (Serpasil) is a tranquilizer; he had been using it to treat high blood pressure. Soon physicians will use the two drugs together for patients who are severely disturbed, expecting to grant patients a double measure of tranquility, although serious side effects will come to plague many of the patients on either drug. *See also* 1950 MED.

Swedish surgeon Per-Ingvar Bränemark observes that a titanium microscope he is using to study bone tissue has bonded to the bone. Following up on this discovery, he learns by 1965 how to make dental implants that bond to the jawbone. *See also* 1918 MED.

Virginia Apgar [b. Westfield, New Jersey, June 7, 1909, d. New York City, August 7, 1974] introduces the Apgar score, which predicts the health of a newborn baby by measuring the pulse, respiration, muscle tone, color, and reflexes. Its use soon becomes universal in the United States as well as in much of the rest of the world. *See also* 1944 MED.

British doctor Douglas Bevis

[b. Ealing, England, May 28, 1919, d. June 25, 1994] develops amniocentesis, a method of examining the genetic heritage of a fetus while it is still in the womb by sampling the fluid from inside the amniotic sac. *See also* 1958 MED.

Jean Dausset [b. Toulouse, France, October 10, 1916] discovers that people who have had repeated blood transfusions eventually develop antibodies to the blood being transfused, an observation later used in typing tissue for organ transplants. *See also* 1953 MED; 1980 MED.

The first sex-change operation is performed on George Jorgenson [b. New York City, May 20, 1926, d. San Clemente, California, May 3, 1989], who becomes known to the world by the post-change name of Christine.

Jonas Edward Salk [b. New York City, October 28, 1914, d. La Jolla, California, June 23, 1995] develops a killed-virus vaccine against polio. It is used for mass inoculations starting in 1954 and successfully prevents the disease, although it is later superseded by a live-virus vaccine developed by Albert Sabin. *See also* 1948 MED; 1955 MED.

Selman A. Waksman of the United States wins the Nobel Prize in physiology or medicine for the discovery of streptomycin.

☒ Physics

David Bohm [b. Wilkes-Barre, Pennsylvania, December 20, 1917, d. October 27, 1992], following an idea originally proposed by Louis de Broglie, develops the guiding-wave theory of quantum mechanics. In this theory, real particles and

real waves simultaneously exist at all times. The real wave, corresponding to the probability wave in the Max Born interpretation of quantum theory, somehow guides the particle in its path. *See also* 1926 PHY.

Sir Frederick Charles Frank predicts that, although icosahedral crystals are impossible, regions of icosahedral symmetry will form in liquids that are cooled below their freezing point. Later work demonstrates that this happens when metals are cooled so fast that they have the structure of glasses (metallic glasses).

Felix Bloch and Edward Purcell of the United States win the Nobel Prize in physics for their measurement of the magnetic moment of a neutron. *See also* 1947 PHY.

I Tools

Donald Glaser [b. Cleveland, Ohio, September 21, 1926] observes cosmic-ray tracks in his bubble chamber, which consists of a small glass bulb filled with ether — inspired by watching the bubbles rise in a glass of beer. *See also* 1960 PHY.

Massachusetts Institute of Technology develops the first numerically controlled tooling machine; it is a standard three-gearied milling machine with a separate numerical control unit. The positions of the tools are controlled by data stored on tape. *See also* 1818 TOOL; 1954 TOOL.

A group led by Hungarian-American physicist Edward Teller [b. Budapest, Hungary, January 15, 1908, d. Stanford, California, September 9, 2003] develops the first thermonuclear device, known as the hydrogen bomb, or H bomb. The bomb, which works by

nuclear fusion, is exploded at the Eniwetok Atoll in the South Pacific on November 6. A fission bomb is used to start hydrogen fuel fusing into helium in a two-story, 50-ton device. Improvements lead to bombs that can be carried on airplanes and in guided rocket missiles. *See also* 1945 TOOL.

1953

► Anthropology

Kenneth Page Oakley [b. Anerham, England, April 7, 1911, d. November 2, 1981] announces that chemical tests on the jawbone of the so-called Piltdown man reveal it to be a fake, an ape jawbone that has been doctored with a chemical to make it look ancient. *See also* 1908 ANTH.

★ Astronomy

Iosif Samuilovich Shklovskii [b. Ukraine, July 1, 1916, d. March 3, 1985] explains the radio emission from the Crab Nebula as being caused by synchrotron radiation. *See also* 1948 AST.

British astronomer Roger C. Jennison develops a way to use very-long-baseline interferometry with radio telescopes that would dramatically improve resolution. As he is a graduate student at the time, the idea is not put into practice. It is rediscovered in 1975 by Alan E. E. Rogers. *See also* 1887 PHY; 1975 AST.

Jerzy Neyman [b. Bendery, Romania, April 16, 1894, d. Oakland, California, August 5, 1981] and Elizabeth Leonard Scott [b. Fort Sill, Oklahoma, November 23, 1917, d. Berkeley, California, December 20, 1988] discover the existence of super-clusters (clusters of clusters) of galaxies. *See also* 1987 AST.

↗ Biology

Rosalind Elsie Franklin [b. London, July 25, 1920, d. London, April 16, 1958] and New Zealand-British physicist Maurice Wilkins make X-ray studies of deoxyribonucleic acid (DNA) that allow James Watson and Francis Crick to determine its structure. Watson and Crick develop the double-helix model for DNA, which explains how the giant molecule is capable of transmitting heredity in living organisms. *See also* 1952 BIO; 1955 BIO.

Harold Urey and Stanley Miller [b. Oakland, California, March 7, 1930] create a sample of the early Earth's atmosphere by causing electric discharges in a mixture of hydrogen, methane, ammonia, and water, producing a "primordial soup" of amino acids and nucleotide bases which may have formed the first living organisms. *See also* 1958 BIO.

Peter Brian Medawar [b. Rio de Janeiro, Brazil, February, 1915, d. London, October 2, 1987] discovers that adult animals who early in life have been injected with cells from another animal will accept tissue grafts from the same animal whose cells were injected. This helps establish Macfarlane Burnet's theory that immunity is gradually developed as the immune system learns to recognize self and nonself. *See also* 1949 MED; 1960 MED.

André-Michael Lwoff [b. Ainay-le-Château, France, May 8, 1902, d. Paris, September 30, 1994] discovers that a bacteriophage attaches itself to the chromosome of a bacterium, causing the bacterium to produce more copies of the virus. *See also* 1965 BIO.

Romanian-American physiologist George Emil Palade [b.

Iasi, Romania, November 19, 1912] describes tiny organelles he has discovered in cells, later to be identified as ribosomes. *See also* 1949 BIO; 1956 BIO.

Austrian-British biochemist Max Ferdinand Perutz [b. Vienna, May 19, 1914, d. Cambridge, England, February 6, 2002] introduces the technique of adding an atom of a heavy element, such as gold, to an organic molecule to improve X-ray diffraction of the molecule. *See also* 1960 CHEM.

John Eccles and coworkers determine that the movement of ions into and out of neurons is the basis of transmission of signals in nerves. *See also* 1951 BIO; 1963 BIO.

Vincent Du Vigneaud assembles in their exact order the eight amino acids in the small protein molecule of the hormone oxytocin (which he had determined in 1947), the main initiator of contraction of the uterus and secretion of milk. It is the first synthesis of a hormone. *See also* 1955 BIO.

Mabel R. Hokin (later Hokin-Neaverson) and Lowell E. Hokin discover that acetylcholine causes cells of the pancreas to increase their uptake of phosphorus groups that are incorporated into the cell membrane. This is an important step toward learning how cells communicate with each other, although it takes about 30 years for biologists to grasp the full import.

Fritz Lipmann of the United States and Hans Krebs of England share the Nobel Prize for physiology or medicine, Lipmann for the discovery of coenzyme A and Krebs for the discovery of the citric acid cycle. *See also* 1945 BIO; 1937 BIO.

Discovering DNA

Today it is common knowledge that DNA, a nucleic acid, directs the development of cells. Scientists gradually learned about DNA in a curiously twisted fashion that is common in science. For one thing, the discovery of DNA required progress on three separate fronts: cytology (the study of cells through a microscope), genetics, and chemistry.

After Gregor Mendel's laws of heredity were rediscovered in 1900, considerable interest developed in what causes heredity. The fundamental structures involved — the chromosomes — had been discovered and studied by Walther Flemming in the 1880s, but no one knew that they were connected to heredity. They were just long thin structures that appeared when cells were stained during cell division. Also, Friederich Miescher had discovered nucleic acids in cell nuclei as early as 1869, but they were not connected either to heredity or to chromosomes — although Miescher's later discovery that salmon sperm are almost entirely nucleic acid should have been a clue to the connection.

In 1907 Thomas Hunt Morgan, who was somewhat skeptical about genetics, began to use fruit flies in breeding experiments. Within a short time he found that Mendel's laws worked, but also that some inherited characteristics appeared to be linked together. These linkages behaved as if the units of heredity, the genes, lined up in long rows. A suitable long thin part of the cell that could physically contain the genes was the chromosome, as had earlier been suggested on other grounds by August Weismann. By 1911 Morgan was able to show that genes strung along the chromosomes are the agents of heredity.

While this development was occurring on the genetic front, there was also some progress being made in chemistry. In 1909 Phoebus Aaron Theodor Levene was the first to determine that nucleic acids contain a sugar, ribose. Twenty years later, he found that other nucleic acids contain a different sugar, deoxyribose. Hence, there are two types of nucleic acid: ribonucleic acid (RNA) and deoxyribonucleic acid (DNA). Levene also worked out the other compounds that were in RNA and DNA. This chemistry was then explored in detail in the 1930s by Alexander Todd.

Chromosomes, like other cell structures, contain proteins. They also contain DNA. Proteins were known to be complex molecules that are biologically very active, so everyone thought that genes must be proteins — until 1944 when Oswald Avery and coworkers showed that hereditary characteristics could be induced by pure DNA, without a protein involved.

By the early 1950s a few scientists from different fronts were tackling the problem of understanding DNA. Among these was Linus Pauling, who was at the time probably the most accomplished chemist. In 1951 Pauling, working with Robert Corey, determined that the structure of a class of proteins is a helix, which is a three-dimensional spiral. This was the first determination of the physical structure of a large biological molecule. At

about this time, Pauling turned to the study of DNA, hoping to discover its structure as well.

In England, there were several scientists interested in the structure of DNA. Maurice Wilkins and Rosalind Franklin were doing X-ray diffraction studies of DNA in hopes of elucidating its structure. Diffraction studies had proved successful in analyzing crystal structures, and DNA could be crystallized.

Another English scientist interested in the subject was Francis Crick, a 35-year-old graduate student. With an undergraduate degree in physics, he too would have liked to do X-ray diffraction studies; but English custom kept him from competing with Wilkins and Franklin.

A fourth interested scientist was James Watson, an American. Watson was working as a postgraduate student, trying to learn about genetics from studying organisms. But he realized that the solution to the problem was more likely on the chemical front, so he abandoned what he was doing and applied for work in X-ray diffraction. He was lucky to be taken on at the same Cambridge laboratory where Francis Crick was pursuing his degree, not far from London, where Wilkins and Franklin worked.

News of Pauling's discovery of a helical structure in proteins set all the English group (except — at first — Franklin) thinking that DNA might be a helix as well. Alec Stokes, who was working with Wilkins, was the first to think DNA might be a helix, an idea he had developed when he first saw the diffraction studies. Wilkins thought it might be several helices twisted together.

Watson and Crick decided to try using the method by which Pauling had found the helix in proteins. He had stuck together models of the subunits of the molecule, rather as one puts a tinker toy set together. The models need to be constructed so that they fit together according to Pauling's theory of the chemical bond. Watson and Crick acquired a copy of Pauling's 1939 book on the chemical bond and came up with a model for DNA of three helices twisted together. But when they showed it to Wilkins and Franklin, Franklin pointed out that it disagreed with her diffraction data and had other deficiencies as well.

Watson gradually established to his and Crick's satisfaction that DNA does have a helical structure. Crick figured out that the bases in DNA are always paired in the same way. Franklin insisted on the correct location of the sugars.

Meanwhile, Pauling produced two versions of his model of DNA. It contained three twisted helices and was clearly wrong. One of the best chemists of the century had made a mistake in his chemistry.

After another false step, Watson finally built a model that incorporated two helices, paired bases, and the sugar structure recommended by Franklin. Crick did calculations that showed that this model was feasible. Wilkins and Franklin produced X-ray diffraction calculations that confirmed the structure. On a visit to Cambridge, Pauling agreed. The true nature of DNA had finally been discovered.



James Dewey Watson
[b. Chicago, Illinois, April 6, 1928]

X-ray diffraction studies from the late 1940s and early 1950s implied that the DNA molecule might be a helix (spiral). Using this and other evidence, Watson and Francis H.C. Crick concluded that DNA is a double helix, consisting of two complementary chains wound around each other and attached by their nucleotide bases. In 1968 Watson became director of the Cold Spring Harbor Laboratory on Long Island and directed it in studies of genes that cause cancer. From 1989 through 1992 he was director of the Human Genome Project in the United States, which produced one of the first maps of the human genome.

Francis Harry Compton Crick

[b. Northampton, England, June 8, 1918]

After service in World War II, Crick worked at the Cambridge Medical Research Council Unit on the use of X-ray crystal diffraction to determine the structure of large biological molecules. He teamed with James D. Watson in 1951 and the two together worked out the double-helix structure of DNA based on Crick's theories and X-ray diffraction studies prepared by Rosalind Franklin. After this breakthrough, Crick worked with Sydney Brenner on decoding DNA's method of producing amino acids and other projects in genetics. His theories of the nature of consciousness and the origin of life have had considerable influence on all workers in those fields.



Chemistry

Karl Ziegler [b. Helsa, Germany, November 26, 1898, d. Mülheim (Germany), August 12, 1973] develops the first catalyst that combines monomers into a polymer in a regular fashion, producing a much stronger and more resistant polyethylene. Upon hearing of Ziegler's discovery of a way to catalyze the reactions that produce plastics with metal ions, Giulio Natta [b. Imperia, Italy, February 26, 1903, d. Bergamo, Italy, May 2, 1979] uses the idea to develop the first isotactic polymers (long repeated hydrocarbon molecules that have a carbon chain with attachments that are all on one side of the chain). See also 1963 CHEM.

Henry Taube [b. Neudorf, Saskatchewan, Canada, November 30, 1915] deter-

mines the electron transfer mechanism that occurs when metals (such as cobalt or chromium) dissolve in water, forming complexes of metal ions surrounded by water ions. See also 1983 CHEM.

Herbert A. Hauptman [b. New York City, February 14, 1917] and Jerome Karle [b. New York City, June 18, 1918] introduce probabilistic methods as the essential tools for determining phases for centrosymmetric crystals. See also 1985 CHEM.

Communication

Commercial color television begins in the United States with a few broadcasts toward the end of the year on the Columbia Broadcasting System (CBS) and most major programs on the National Broadcasting Company

(NBC) in color. The Radio Corporation of America, owner of NBC, had developed the compatible (so-called because broadcasts could also be received by existing black-and-white only sets) color television system. CBS, which had developed a separate, incompatible system, abandons its technology for the compatible one. See also 1929 COMM; 1955 COMM.

J. Halcombe Laning, Jr. [b. Kansas City, Missouri, February 14, 1920] and Neal Zierler [b. Baltimore, Maryland, September 17, 1926] develop the first algebraic compiler. It runs on the Whirlwind computer at MIT and translates algebraic expressions into programs that are interpreted by a floating-point interpreter. See also 1951 COMM.

Computers

Jay Forrester develops the ferrite core memory for computers; core memories are installed in the IBM Type 704 and 705 computers a year later. Kenneth H. Olsen [b. Stratford, Connecticut, 1926] builds the first computer equipped with a ferrite core memory. The computer is called MEMORY TEST and performs tasks for the SAGE military operation. See also 1951 COMP; 1953 COMM.

The IBM 650 computer is introduced. Also called the Magnetic Drum Calculator, it is the first computer to be manufactured in large numbers. Derived from the IBM 701, the IBM 650 has a memory of 1000 ten-byte words. Some 1500 units are sold before it is taken out of production in 1969. See also 1952 COMP; 1956 COMP.

Earth science

Maurice Ewing announces that there is a great rift running down the middle of the mid-Atlantic ridge. See also 1925 EAR; 1956 EAR.

Sir Edmund Percival Hillary [b. Auckland, New Zealand, July 20, 1919] and guide Tenzing Norgay [b. Tsa-chu, Nepal, 1914, d. May 9, 1986] reach the summit of Mount Everest, the world's highest mountain, on May 29.

Ecology & the environment

Zoologist Nikolaas Tinbergen [b. The Hague, Netherlands, April 15, 1907, d. Oxford, England, December 21, 1988], one of the founders of the new science of ethology, publishes *The Herring Gull's World*, in which he discusses courtship and

other behaviors of herring gulls. He discovers the importance of animal interactions based on the submissive posture. *See also* 1973 ECOL.

Smog in New York City is believed responsible for 200 deaths. *See also* 1952 ECOL; 1957 ECOL.

Eugene Pleasants Odum [b. Lake Sunapee, New Hampshire, September 17, 1913, d. Athens, Georgia, August 9, 2002] publishes *Fundamentals of Ecology*, in which he claims that ecosystems are the basic units of ecology. *See also* 1954 ECOL.

► Energy

The United Kingdom decides to build its first nuclear power plant for production of electric power on an industrial scale. The carbon-dioxide-gas-cooled reactor planned for Calder Hall will also produce plutonium for use in nuclear weapons. *See also* 1950 ENER; 1956 ENER.

Stored nuclear energy in graphite, a phenomenon first detected but not recognized in 1949 by N.J. Pattenden, begins to be employed as an adjunct power source at the Windscale (now Sellafield) nuclear power plant in England. *See also* 1950 ENER; 1957 ENER.

◆ Materials

The first artificial diamonds are made on February 16 by a team in Sweden using high heat and pressure. Although they repeat the experiment several times, they do not announce the discovery and credit usually goes to a team at General Electric who will make their first diamonds almost two years later. *See also* 1954 MATR.

For the first time, sales of detergents in the United States

are higher than sales of soaps. *See also* 1916 MATR.

Hermann Staudinger of Germany wins the Nobel Prize in chemistry for his study of polymers. *See also* 1926 MATR.

♥ Medicine & health

On May 6 John Gibbon uses his heart-and-lung machine to keep Cecelia Bavolek alive while operating successfully on her heart. It is the first use of the machine on a human being. *See also* 1951 MED; 1967 MED.

The first human-to-human kidney transplant is performed in Paris. The graft fails after 21 days because of rejection. *See also* 1963 MED.

Alfred Kinsey and coworkers produce a landmark study of sex practices of U.S. women. Among the conclusions: Almost half have sexual relations before marriage, a quarter are unfaithful afterward, and a quarter of those unmarried have had homosexual relationships. *See also* 1948 MED.

Evarts Ambrose Graham [b. Chicago, Illinois, March 19, 1883, d. St. Louis, Missouri, March 4, 1957] and Ernest L. Wydner [b. Herford, Germany, April 30, 1922, d. July 14, 1999] demonstrate that tars from tobacco smoke cause cancer in mice. *See also* 1775 ECOL; 1964 MED.

Sleep researchers led by Nathaniel Kleitman [b. Kishinev, Russia, April 26, 1895, d. Beverly Hills, California, August 13, 1999] discover rapid eye movements (REM) during sleep. The discovery starts when Kleinman's graduate student Eugene Aserinsky [b. 1921, d. 1998], while studying sleep patterns in his eight-year-old son Armond with an electroencephalograph, observes periods of rapid eye movement in normal sleep. The REM periods are later found to be associated with vivid dreams.

⌘ Physics

Murray Gell-Mann introduces in August a system of assigning isospin to particles, a new quantum number that relates particles to each other in pairs or triplets. Isospin — a.k.a. isotopic spin — leads immediately to the concept of strangeness and eventually to the "eightfold way." Later this year Tadao Nakano and Kasuhiko Nishijima suggest the same system of isospin. *See also* 1948 PHY; 1961 PHY.

☒ Tools

American physicist Charles Hard Townes [b. Greenville, South Carolina, July 28, 1915] develops the maser (short for microwave amplification by

stimulated emission of radiation), the precursor of the laser. In the device microwaves are amplified by stimulating emission at the same wavelength in ammonia gas molecules that have been excited (that is, boosted to a higher energy level). *See also* 1912 PHY; 1964 TOOL.

Robert Frank Borkenstein [b. Fort Wayne, Indiana, August 31, 1912, d. Bloomington, Indiana, August 20, 2002] invents the Breathalyzer, a portable device for measuring from exhaled gases the amount of alcohol a person has consumed.

Frits Zernike of the Netherlands wins the Nobel Prize in physics for his development of the phase-contrast microscope. *See also* 1930 TOOL.

↗ Transportation

Irmgard Flugge-Lotz [b. Hameln, Germany, July 16, 1903, d. May 22, 1974] publishes *Discontinuous Automatic Control*. The book introduces the mathematical foundation for automatic aircraft control, which Flugge-Lotz had started developing during World War II. The work is based on the differential equations that describe boundary-layer problems in fluid dynamics.

Murray Gell-Mann

[b. New York City, September 15, 1929]

The development of the concept of strangeness for particles when he was 24, which explained why particles in cosmic rays did not decay according to previous theories, showed two characteristics of Gell-Mann's later work: truly innovative ideas in particle physics and a penchant for unusual names for his discoveries. His next triumph, the classification scheme for baryons (heavy subatomic particles), was termed the eightfold way. His most famous name and discovery is quarks for the fundamental particles underlying all medium and heavy particles. Less well known is his work on neutral currents, a manifestation of the weak force.



German engineer Eugen

Sänger proposes the use of photons (particles of light) for the propulsion of spaceships, later to be realized as the solar sail. *See also* 1984 TRAN.

Michelin of France and Pirelli of Italy introduce radial-ply tires. *See also* 1947 TRAN.

John W. Hetrick patents the first type of air bag as a safety device for automobiles. *See also* 1957 TRAN.

1954

▲ Archaeology

On May 26 Kamal el-Mallakh [b. Assuit, Egypt, October 26, 1918, d. October 1987] and other archaeologists find two nearly identical chambers near the base of the Great Pyramid of Khufu in Egypt. Excavating one of them, while leaving the other untouched for future work, they uncover a dismantled 43-m (142-ft) cedar boat. It is not a total surprise, since ancient records referred to these boats, known as solar boats, as carrying the Pharaoh's soul to the Sun. *See also* 4000 BCE TRAN.

❖ Biology

Joe Hin Tjio [b. Java, November 2, 1919, d. November 27, 2001] and Albert Levan show that humans have 46 chromosomes rather than 48, as was believed previously. *See also* 1918 BIO; 1959 MED.

John Enders, Thomas Weller, and Frederick Robbins win the Nobel Prize in physiology or medicine for their discovery of a method for cultivating viruses in tissue culture. *See also* 1948 MED.

▷ Chemistry

Georg Wittig [b. Berlin, June 16, 1897, d. Heidelberg, West Germany, August 26, 1987] develops the Wittig reaction, in which an aldehyde or ketone reacts with an organic phosphorus compound. The reaction will become widely used in organic synthesis, for example as a step toward synthesizing cholesterol or vitamin D. *See also* 1979 CHEM.

Linus Pauling of the United States wins the Nobel Prize in chemistry for his work on chemical bonds. *See also* 1939 CHEM.

☛ Communication

John Backus [b. Philadelphia, Pennsylvania, December 3, 1924] publishes a preliminary report, *Specifications for the IBM Mathematical FORMula TRANslating System-FORTRAN*, which marks the beginning of the development of true programming languages. *See also* 1949 COMM; 1956 COMM.

Earl Masterson [b. April 13, 1916, d. April 16, 2002] develops the Uniprinter for use with computers. Called a line printer, it is capable of printing 600 lines per minute. *See also* 1884 COMM; 1970 COMM.

I.D.E.A. introduces the world's first commercial pocket-sized transistor radio, the Regency TR-1, on October 18.

▀ Computers

The UNIVAC 1103A is the first commercial computer equipped with a ferrite core memory. It is 50 times faster than the UNIVAC 1101 of 1951. *See also* 1953 COMP.

The SAGE (Semi Automatic Ground Environment) system

is instituted by the U.S. air force. It will collect data from radar stations and other sources that will then be processed by the Whirlwind computer system in real time. The system will not be fully operational until 1963. *See also* 1951 COMP.

Allen Newell [b. San Francisco, March 19, 1927, d. July 19, 1992] and Herbert Alexander Simon [b. Milwaukee, Wisconsin, June 15, 1916, d. Pittsburgh, Pennsylvania, February 9, 2001] conceive of the use of computers to develop theories of problem solving and other human behaviors. They help found artificial intelligence, developing the first working AI program. *See also* 1938 COMP; 1956 COMP.

⊕ Earth science

Elso Sterrenberg Barghoorn [b. New York City, June 30, 1915, d. 1984] and Stanley A. Tyler [b. 1906, d. 1963] discover tiny fossils in the 2,000,000,000-year-old Gunflint chert of the Canadian shield. The fossils resemble modern monerans, such as bacteria and blue-green algae and are 1,500,000,000 years older than any previously known. *See also* 1968 EAR.

⊗ Ecology & the environment

In one of the first comprehensive studies of an ecosystem, brothers Eugene and Howard T. Odum [b. 1924, d. Gainesville, Florida, September 11, 2002] begin to study a coral atoll in the Pacific, showing the importance of a delicately balanced nutrient cycle to the survival of a coral reef. *See also* 1953 ECOL.

Aikichi Kaboyama, a Japanese fisher, is killed by fallout from

a U.S. test of a thermonuclear bomb in the Pacific. *See also* 1954 TOOL; 1963 ECOL.

≡ Electronics

Gordon Teal at Texas Instruments introduces the silicon transistor, which is much cheaper to manufacture than previously used germanium-based versions. *See also* 1951 ELEC; 1961 ELEC.

↗ Energy

The Soviet Union completes the first small nuclear reactor that is intended primarily to produce electric power. *See also* 1952 ENER; 1957 ENER.

As a part of the Atoms for Peace Program of the United States, President Dwight David Eisenhower in September waves a radioactive wand (a neutron source) in front of a detector that starts groundbreaking for the Shippingport Atomic Power Station in Pennsylvania. This will become the first commercial nuclear power plant in the United States. *See also* 1952 ENER; 1957 ENER.

Bell Telephone scientists Daryl Chapin, Calvin Souther Fuller [b. Chicago, May 25, 1902, d. 1994], and Gerald Pearson [b. Salem, Oregon, March 31, 1905, d. October 25, 1987], following an idea put forward this year by Paul Rappaport, develop the silicon photovoltaic cell, which can produce electric power from sunlight. *See also* 1839 ENER; 1981 ENER.

❖ Materials

The first artificial diamonds to be offered for sale for industrial use are produced on December 16 in the United States by a team headed by Tracy Hall along with staff

Nuclear power

After World War II, governments instituted a search for peaceful uses for nuclear energy. Comic books on "the atom" informed children that the atomic energy in a steamship ticket is enough to circle the globe hundreds of times, raising the expectations of a generation. Scientists designed nuclear reactors that some expected would become sources of unlimited power.

According to Lewis Strauss, chairman of the Atomic Energy Commission (AEC) in 1954, electricity from nuclear power would be "too cheap to meter."

The initial use of nuclear reactors was not peaceful, however. The first energy-producing reactors powered nuclear submarines, first launched by the United States in January 1954.

The Soviet Union completed in June 1954 a small reactor that delivered the first peaceful application of nuclear energy, but not in practical amounts. In the United States, experimental and submarine reactors were connected to the electric power grid in June 1955. In England a 50,000-kilowatt reactor, known as Calder Hall, started operation in October 1956.

Since then, nuclear reactors have been built in many countries. In some, such as Japan and France, nuclear power is now the main source of energy. This development made these countries independent from the use of imported oil, supplies of which can be disturbed by political crises.

Enthusiasts have heralded nuclear energy as ecologically sound because it does not produce carbon dioxide that causes global

warming. However, the partial meltdown of a nuclear reactor at the Three Mile Island power plant near Harrisburg, Pennsylvania, in 1979 and the reactor explosion in Chernobyl (Ukraine) in 1986 showed that nuclear energy carries with it the potential for disaster. A second problem is cost; despite Strauss's prediction, nuclear energy is more expensive to generate than energy from fossil fuel. A third major problem is disposal of radioactive waste fuel, some parts of which remain dangerously radioactive for thousands of years.

During the 1970s, engineers began to design nuclear reactors to incorporate passive safety systems. Such systems use cooling methods that rely on gravity alone and do not require pumps that can break down. In one design, reactor vessels would be submerged in tanks of boron-laced water that would flood the reactor immediately in the case of a problem, stopping the nuclear reactions. But in the United States, at least, such designs have not been carried out. Only two new power plants have been built in the United States since 1990, partly as a result of concern for their safety, but also for economic reasons. Despite this, the United States remains the leader both in number of operating reactors and power generated.

A new concern surfaced after September 11, 2001, when it became apparent that terrorists commandeering airplanes might crash into a nuclear power plant or might try to damage such a plant with conventional explosives. Even surface dumps for nuclear waste could damage a wide region around them if struck with a large bomb. Calls for shutting down plants near heavily populated regions increased.

members of the General Electric Company. The diamonds are produced from carbon by pressure and heat and are immediately put on sale. *See also* 1953 MATR.

♥ Medicine & health

On March 26 Clarence Walton Lillehei [b. Minneapolis, Minnesota, October 23, 1918, d. St. Paul, Minnesota, July 7, 1999] performs the first successful open-heart surgery on a child, using the child's parent's heart to keep the child's blood oxygenated. *See also* 1914 MED.

A surgical team headed by Joseph Murray [b. Milford, Massachusetts, April 1, 1919] performs the first successful kidney transplant, between

identical twins. *See also* 1953 MED.

Frederick Sanger [b. Rendcombe, England, August 13, 1918] becomes the first to determine the molecule-by-molecule structure of a protein, insulin (published in 1955). *See also* 1921 MED; 1958 CHEM.

⌘ Physics

The *Centre Européen de Recherche Nucléaire* ("European Center for Nuclear Research"), known as CERN, is founded on September 29. It is an international center for work in particle physics, situated on the border between France and Switzerland.

Chinese-American physicist

Chen Ning (Frank) Yang [b. Hefei, China, September 22, 1912] and Robert Lawrence Mills in June establish the basis for modern quantum field theory by developing the mathematical characteristics of the kind of field needed to allow symmetry to produce new particles. It is called a Yang-Mills gauge-invariant field. *See also* 1964 PHY.

It is discovered in November that the neutral K particle (a.k.a. neutral kaon) and its antiparticle decay in a way that seems to violate the laws of physics. *See also* 1956 PHY.

In November Abraham Pais introduces the name *baryon* to describe heavy particles that are affected by the strong

force. Mesons, also affected by the strong force, are excluded (the term *hadron* will later be used for all particles affected by the strong force, including mesons). *See also* 1935 PHY; 1962 PHY.

Max Born of England and Walther Bothe of Germany share the Nobel Prize in physics, Born for his work in quantum mechanics and Bothe for his work in cosmic radiation. *See also* 1925 PHY; 1929 PHY.

█ Tools

Luis Alvarez develops the liquid-hydrogen bubble chamber and observes tracks caused by subatomic particles. *See also* 1952 TOOL.

The first true hydrogen bomb is exploded by the United States on Bikini Atoll in the South Pacific; the power of the blast is expected to be 7 megatons, but proves to be 15. *See also* 1954 ECOL; 1957 TOOL.

The Bevatron particle accelerator at the Radiation Laboratory in Berkeley (renamed the Lawrence Berkeley Laboratory in 1958) is completed. It can accelerate uranium atoms to 6,500,000,000 electron volts (6.5 GeV). *See also* 1943 TOOL; 1966 TOOL.

Various manufacturers build highly automated factories; Ford builds a 40-worker factory for engine blocks that has the same output as an older factory needing 117 workers; Raytheon's new radio plant replaces 200 workers with 2, who between them assemble 1000 radios a day; and a machine for forming cups from aluminum strips replaces 55 workers with 1.

→ Transportation

John Robinson Pierce [b. Des Moines, Iowa, March 27, 1910, d. Sunnyvale, California, April 2, 2002] publishes in *Jet Propulsion* an article explaining the importance of a geostationary orbit for Earth satellites. *See also* 1945 COMM; 1960 COMM.

The first atomic-powered submarine, the USS *Nautilus*, built by Admiral Hyman Rickover, is commissioned; sea trials start January 17, 1955. *See also* 1947 TRAN; 1957 ENER.

Malcolm MacLean starts using containers for transporting goods between New York and Houston; these containers can be loaded onto trucks and ships. Container transport spreads quickly

throughout the world by 1965 and now displaces most other forms of transport of goods. *See also* 1915 TRAN.

The first vertical-take-off plane is developed in Great Britain, where it is known as the "flying bedstead." *See also* 1939 TRAN.

1955

★ Astronomy

Jan Hendrik Oort measures the polarization of light coming from the Crab Nebula, confirming that it is synchrotron radiation. *See also* 1953 AST.

Martin Ryle describes to the Royal Astronomical Society his work with the first specially constructed radio interferometer, a device that increases the ability of radio telescopes to resolve radio sources. With interferometry, radio telescopes become as good as or better than light telescopes at resolving light sources. *See also* 1946 AST; 1960 AST.

Fred Hoyle and Martin Schwarzschild calculate the evolution of a star that has exhausted the hydrogen at its center, showing that the star becomes a red giant. *See also* 1913 AST.

↗ Biology

Spanish-American biochemist Severo Ochoa [b. Luarca, Spain, September 24, 1905, d. Madrid, November 1, 1993] develops enzymes that cause nucleic acid bases to form RNA, essentially creating synthetic RNA. *See also* 1909 CHEM; 1959 BIO.

James Bonner and Paul Ts'o isolate mitochondria from cells. *See also* 1951 BIO.

German biochemist Heinz Fraenkel-Conrat [b. Breslau

(Wrocław, Poland), July 29, 1910, d. Oakland, California, April 10, 1999] shows that viruses consist of a noninfective protein coat and an infective nucleic acid core. Fraenkel-Conrat and Robley Cook Williams [b. 1908, d. Oneonta, New York, January 3, 1995] assemble the tobacco mosaic virus from purified parts of the virus. *See also* 1937 BIO.

Edmond H. Fischer [b. Shanghai, China, April 6, 1920] and Edwin G. Krebs [b. Lansing, Iowa, June 6, 1918] discover reversible protein phosphorylation, a biological regulatory mechanism that starts and stops a variety of cellular functions. *See also* 1992 BIO.

Axel Theorell of Sweden wins the Nobel Prize in physiology or medicine for his study of oxidation enzymes. *See also* 1935 BIO.

▷ Chemistry

Albert Ghiorso and coworkers synthesize element 101, mendelevium (Md), named after Dmitri Mendeleev, who developed the periodic table. The element is created by bombarding an isotope of einsteinium with alpha particles. It is the first element ever to be identified from a single atom.

Vincent Du Vigneaud of the United States wins the Nobel Prize in chemistry for his synthesis of polypeptide hormones. *See also* 1953 BIO.

⌚ Communication

Indian scientist Narinder S. Kapany [b. Moga, India, March 1927] discovers that a glass fiber surrounded by a cladding, known as an optical fiber, can conduct light over great distances with little loss of intensity. *See also* 1966 COMM.

Jack Gilmore completes the TX.O, a human-machine interface using a CRT tube for display, an optical pen, a flexowriter, and function keys. It is the precursor of the modern video terminal. *See also* 1960 COMM.

Emmet Leith, while working on the problem of improving radar images taken by airplanes, accidentally rediscovered holography. *See also* 1947 COMM; 1958 COMM.

💻 Computers

Bell Telephone builds the first computer using transistors instead of electron tubes. *See also* 1954 COMP; 1956 COMP.

㊣ Ecology & the environment

A study of asbestos textile workers in London establishes a link between asbestos exposure and lung cancer. *See also* 1957 ECOL.

U.S. paint manufacturers limit lead in paint to 1 percent or less. *See also* 1917 MED; 1971 ECOL.

⚡ Energy

Electricity generated by nuclear power is used for the first time in the United States on July 17 in Arco, Idaho — from an experimental reactor at the U.S. National Reactor Testing Station — and on July 18 in Schenectady, New York — from a prototype nuclear submarine reactor in West Milton, New York. Chairman of the U.S. Atomic Energy Commission Lewis Strauss [b. Charleston, West Virginia, January 31, 1896, d. January 21, 1974] predicts that soon electricity produced by nuclear power plants will be "too cheap to meter." *See also* 1952 ENER; 1957 ENER.

The core of the nuclear reactor EBR-1 is destroyed on November 29 when an operator accidentally fails to drop the cooling rods in response to reactor overheating. *See also* 1951 ENER; 1957 ENER.

Food & agriculture

Tractors outnumber horses in the United States for the first time in history. *See also* 1924 FOOD.

R.C. Brian, R.F. Homer, J. Stubbs, and R.L. Jones of Imperial Chemical Industries (ICI) in Great Britain find that a substance prepared by

fellow ICI chemist R.J. Fielden is a powerful herbicide that kills the tops of plants (but not the roots or underground stems) and is completely neutralized by contact with ordinary soil. The herbicide, christened *diquat*, can kill established weeds without touching seedlings that have not yet emerged. *See also* 1945 FOOD; 1967 FOOD.

Tappan introduces the first microwave oven designed for home use. Although aimed at the home market, it is still a large and costly luxury item.

See also 1953 FOOD; 1947 FOOD.

Materials

Walter F. Lorch uses renewable cartridges of ion-exchange resins in a device that purifies and softens water.

Mathematics

Henri Cartan [b. Nancy, France, July 8, 1904] and Samuel Eilenberg [b. Warsaw, Poland, September 30, 1913, d. New York City, January 30, 1998] develop homological algebra, a cross between abstract algebra and algebraic

topology that helps unify mathematics.

Karl Prachar [b. 1924, d. November 27, 1994] proves that there are many numbers that are one less than a prime number that have a large number of prime factors. *See also* 1937 MATH; 1980 MATH.

Medicine & health

The success of the Salk polio vaccine is announced on April 12. Soon after, massive immunization programs are initiated in the United States. *See also* 1957 MED.

Stopping an epidemic

Poliomyelitis, commonly called polio, was first described in 1789, but not fully recognized until 1840. In the United States, it first became a feared disease when a small epidemic in 1894 struck Vermont, because it singled out children and often caused paralysis or death. A larger outbreak began in 1916, also striking the East Coast. Franklin D. Roosevelt, later president of the United States, was paralyzed from the waist down by the disease in 1921. Another large outbreak hit the West Coast in 1934. In the late 1940s and early 1950s, a major epidemic of the disease struck the entire United States, infecting tens of thousands each year.

As early as 1908, the cause of polio had been identified — a virus. Jonas Salk, a medical doctor, had worked on the vaccine for the influenza virus during the 1940s. As the head of the Virus Research Laboratory at the University of Pittsburgh School of Medicine, he began the study of the virus causing polio. He confirmed the existence of three types of polio viruses and started growing them in cultures of monkey kidney tissue. He prepared vaccines by killing these viruses with formaldehyde. The killed viruses did not cause the disease, but did stimulate the production of antibodies that protect the human organism against the disease.

In 1952 Salk tested the vaccine on children who had already experienced polio and thus were immune to the virus. The vaccine increased the amount of antibodies in these children, elevating their immunity. The first trial on children who never had polio took place in 1954; it showed the vaccine to be safe and

effective. Throughout the 1950s the incidence of polio was reduced drastically worldwide as a result of the Salk vaccine. By 1957 the number of new cases of the disease in the United States had been reduced from 35,000 in 1953 to 5600.

Albert Sabin, a medical doctor who also had studied the polio virus, prepared a different vaccine containing a live strain of a virus. This virus also stimulates the production of antibodies but is too weak to cause the disease itself. The Sabin vaccine, which (unlike the Salk vaccine) can be administered orally, was tested in large-scale trials in 1957 in the United States and other countries. It was adopted in the Soviet Union and Europe in 1959, and was approved in the United States in 1961. It has two advantages over the Salk vaccine — it can be administered orally and, since it is alive and therefore infectious, it provides some immunity to persons who come in contact with the one who takes the vaccine. By 1964, two years after introduction of the Sabin vaccine, the number of new cases in the United States was reduced to 121 and by 1979 there were no new cases at all that originated in the United States.

Around the world, however, the majority of people were still unvaccinated, so as many as 350,000 cases a year were still occurring in the late 1980s. In 1988 the World Health Organization (WHO) initiated a drive to eradicate polio completely, as another virus-borne disease, smallpox, had been defeated by vaccination. By 2003 the disease had been eliminated (except for isolated cases) everywhere except India, Pakistan, and Nigeria, with fewer than 300 new cases in those nations. At that time, WHO aimed for complete eradication by the end of 2004.

On January 11 Lloyd H. Conover [b. Orange, New Jersey, June 13, 1923] patents tetracycline, the first antibiotic made by chemically modifying a naturally produced drug. It soon becomes one of the most useful antibiotics for treatment of a number of infectious diseases. *See also* 1947 MED.

❖ Physics

Owen Chamberlain [b. San Francisco, July 10, 1920] and Emilio Segrè succeed in producing antiprotons. *See also* 1933 PHY; 1956 PHY.

Abraham Pais and Murray Gell-Mann observe that two varieties of K mesons (a.k.a. kaons) exist. One decays according to a different mode from the other, although they are otherwise apparently the same particle. Since one particle is termed tau and the other theta, the problem becomes known as the tau-theta puzzle. *See also* 1956 PHY.

Willis Lamb and Polykarp Kusch of the United States share the Nobel Prize for physics, Lamb for his measurement of the hydrogen spectrum and Kusch for his study of the magnetic momentum of the electron. *See also* 1947 PHY; 1937 PHY.

I Tools

Luis Alvarez designs a semiautomatic measuring machine for analyzing particle tracks on bubble-chamber photographs. The machine, called Franckenstein, is built a year later by Hugh Bradner and Jack Franck. *See also* 1952 TOOL; 1960 PHY.

The field ion microscope, developed by American

physicist Erwin Mueller, becomes the first instrument that can picture individual atoms. It accomplishes this by releasing ions from the tip of a needle cooled nearly to absolute zero. The ions strike a fluorescent screen, producing an image of the needle tip. *See also* 1903 TOOL; 1978 TOOL.

→ Transportation

The U.S. Vanguard project for launching artificial satellites is announced.

Christopher Cockerell [b. June 4, 1910, d. Hythe, England, June 1, 1999] patents the hovercraft, also known as an air-cushion vehicle or a ground-effect machine. It can travel over water or flat solid surfaces on a cushion of air that it generates. The first experimental hovercraft is tried out in 1959. *See also* 1877 TRAN; 1959 TRAN.

1956

◀ Anthropology

William Clouser Boyd [b. Dearborn, Missouri, March 4, 1903, d. Falmouth, Massachusetts, February 19, 1983], assisted by his wife Lyle, after studies of blood groups extending back into the 1930s, releases a list of 13 “races” of *Homo sapiens* based on blood groups. One surprise is that the Basques of Spain and France appear to be remaining members of an early group that inhabited Europe before the ancestors of other modern Europeans arrived. *See also* 1842 ANTH.

★ Astronomy

Herbert Friedman [b. New York City, June 21, 1916, d.

Arlington, Virginia, September 9, 2000] reports that solar flares are X-ray sources. *See also* 1942 AST.

❖ Biology

Romanian-American physiologist George Emil Palade discovers that small bodies within the cell, now called ribosomes, are mostly ribonucleic acid (RNA); it is soon found that the ribosomes are the locations in the cell where proteins are manufactured. *See also* 1953 BIO; 1974 BIO.

Arthur Kornberg [b. Brooklyn, New York, March 3, 1918] discovers the enzyme DNA polymerase, which plays a role in replication of DNA. *See also* 1957 BIO.

Earl Wilbur Sutherland, Jr. [b. Burlingame, Kansas, November 19, 1915, d. Miami, Florida, March 9, 1974] isolates cyclic AMP (adenosine monophosphate), an intermediate in the cell’s energy cycle and also important in many other reactions. *See also* 1971 BIO.

Rita Levi-Montalcini and Stanley Cohen [b. Brooklyn, 1922] isolate and purify nerve growth factor. *See also* 1952 BIO; 1986 BIO.

▷ Chemistry

Dorothy Hodgkin uses an electronic computer to work out the structure of vitamin B₁₂. *See also* 1949 CHEM; 1964 CHEM.

Yugoslav-Swiss chemist Vladimir Prelog [b. Sarajevo, Yugoslavia, July 23, 1906, d. Zürich, Switzerland, January 7, 1998] with Robert Cahn and Christopher Ingold develops a general system for specifying the stereoisomers of

organic compounds for a given chemical composition. *See also* 1975 CHEM.

Sir Cyril Hinshelwood of England and Soviet physical chemist Nikolay Semenov share the Nobel Prize in chemistry for their parallel work on the kinetics of chemical chain reactions. *See also* 1928 CHEM.

↳ Communication

The first transatlantic telephone cable, linking Scotland with Newfoundland, is put into operation on September 25. The two coaxial cables can carry 37 circuits and there are 51 repeaters in each direction. Before this cable telephone conversations between the United States and Europe were possible only by short-wave radio telephone. *See also* 1927 COMM; 1988 COMM.

Ampex brings its first video tape recorder on the market. It uses a 5-cm (2-in.) tape, quadruplex heads, and a transverse scan. *See also* 1951 COMM; 1979 COMM.

IBM introduces the hard disk for the storage of data. Their system is called RAMAC (Random Access Method of Accounting and Control) and makes use of indices for locating information on the disk. *See also* 1944 COMM; 1970 COMM.

John Backus and a team at IBM complete FORTRAN I, the first full-fledged computer programming language. Previously, computer programs had to be installed in machine language. FORTRAN becomes commercially available in 1957. *See also* 1954 COMM; 1959 COMM.

Higher computer languages

The first large computers, such as the ENIAC, incorporated logic that was part of the circuitry; therefore, they could only be "programmed" to a small extent by changing wiring. These were followed by programmable computers with von Neumann architecture. Instructions were independent of the circuitry. Early programs were entirely written in machine language; that is, each instruction gave the central processing unit (CPU) a specific task to do, typically one such as "move a word from one specified location to another" or "change a bit in a specified location from a 0 to a 1 unless 1 already." During the 1940s and the early 1950s, all computers were programmed in this kind of machine code. Such programming was a difficult and tedious task, requiring good knowledge of how the hardware of a computer works.

The introduction of interpreters was a major breakthrough. Interpreters translate a program written in an easier programming language into machine language. Particular locations in the CPU did not have to be specified, and commands were more closely connected to operations. A big disadvantage of such an interpreter is that it translates the program line by line into machine language, slowing down execution.

A compiler offers a better method for translating programming language into machine language. A compiler translates a whole program into machine language first. When the compiled program is run on the computer, execution time is shortened since there is no translation step going on. Grace Murray Hopper developed one of the first such compilers during the early 1950s.

During World War II, Hopper had been working with Howard Aiken at the Bureau of Ordnance Computation Project at Harvard. Aiken had built the Mark I computer, a huge electro-mechanical calculator. Hopper designed programs for that computer so that it performed complex calculations for the military. In 1945 she and the team at Harvard started developing Mark II. It was in this computer that a moth, in the words of Hopper, "had been beaten to death" by a relay, stopping the computer. The moth ended up Scotch-taped in their lab logbook, with the note "First actual case of bug being found." Even then the word bug denoted something that caused the computer to fail or to produce incorrect calculations.

Hopper created the first compiler for UNIVAC. Hopper's compiler turned programs written in simple English into machine code. Saying that she was going to communicate with a computer in plain English produced general disbelief. Managers had accepted that computers understand numbers; but computers that understand English seemed inconceivable. Although it made the work of programmers much easier, convincing them to use the compiler was not an easy task. They had gotten used to writing machine code. Hopper developed distaste for the phrase "but we've always done it that way."

During the 1950s several experimental and mostly mathemati-

cally oriented languages appeared. The first one that gathered wide success was FORTRAN (FORmula TRANslator). Developed in 1956, it underwent several changes and is still used today in technical and scientific applications.

Several other languages with different orientations appeared. One of them, COBOL, was developed in 1959 by Grace Hopper for business applications. BASIC, a programming language developed by the mathematicians John Kemeny and Thomas Kurtz at Dartmouth University in 1965, was first used as an educational tool, but became in the late 1970s the most popular language for the personal computer.

BASIC, and to a lesser degree FORTRAN, was often criticized because of the use of loops and branches. These produced the inconvenience that when a program grew to any length, it became more and more entangled, a phenomenon called spaghetti. A minor change anywhere in the program could have uncontrollable repercussions in the whole program, requiring tedious searches and rewriting, a process called debugging.

Languages that allow structured programming were a solution to the spaghetti problem. ALGOL, developed by an international committee, and Pascal, written by Niklaus Wirth, are such languages. These languages require that the coding be organized in logical groups, making reading and amending programs much easier.

In these languages, the software itself and the data are entirely separated. In a more recent approach, data and logical procedures are grouped into discrete units called objects. The first of these object-oriented languages was Simula I, developed in 1965. Its successors, Simula languages designed for various specific computers, introduced the concepts of "object" and "class," in which classes are objects that have similar properties. Groups of objects, or classes, can be related by inheriting characteristics from one group to its successors. SMALLTALK, which used many of the ideas behind Simula, introduced communication between objects; a later version of SMALLTALK incorporated the concept of inheritance. These concepts, which became well known with the advent of object-oriented languages, had been invented early in the 20th century by mathematicians who could not have foreseen their eventual application to computers.

Object orientation has been termed a revolution in software development. Because objects can be used independently in software development, they can also be reused as building blocks, allowing much faster development of software systems. Several other object-oriented languages have been written; among the better-known are C++, Eiffel, Object Pascal, and Clascal.

JAVA, introduced by Sun Microsystems in 1995, takes a different approach. It is designed so that programmers write an application once and the program runs on any computer platform, including Windows, Macintosh, and Linux. Although Microsoft tried to modify a version of JAVA to be specific to their Windows operational system, this was overturned by Sun as part of a lawsuit against the Microsoft monopoly in personal computers operating systems.

John McCarthy [b. Boston, Massachusetts, September 4, 1927] starts work on a list processor, later known as LISP, the computer language of artificial intelligence. The language is based on the list processing language, IPL (information processing language), developed by Herbert A. Simon, Allen Newell, and J. Cliff Shaw. Newell and Simon present their program Logic Theorist at a summer seminar at Dartmouth, where McCarthy coins the term "artificial intelligence." *See also* 1954 COMP; 1957 COMP.

Computers

UNIVAC introduces the first commercially available computer of the second generation; it uses transistors instead of vacuum tubes, making operation less costly and more reliable. *See also* 1955 COMP; 1960 COMP.

Stanislaw Marcin Ulam [b. Lemberg, Poland (now Lvov, Ukraine), April 3, 1909, d. Santa Fe, New Mexico, May 13, 1984] and Paul Stein program a computer to play a form of chess on a 6×6 board. The program, called MANIAC I, becomes the first computer program to beat a human in a game. *See also* 1958 COMP.

Earth science

Bruce Charles Heezen, American oceanographer and geologist [b. Vinton, Iowa, April 11, 1924, d. off coast of Iceland, June 21, 1977] and Maurice Ewing discover the mid-oceanic ridge, a globe-girdling formation of mountains and rifts. As in the part in the Atlantic Ocean, the other parts of the mid-ocean ridge have a deep rift in the center

of the ridge. *See also* 1953 EAR; 1962 EAR.

Ecology & the environment

The first leak of stored high-level radioactive wastes is detected at the Hanford site near Richland, Washington. *See also* 1957 ECOL.

Minamata disease, a nervous system disorder afflicting people living around Minamata Bay in Japan, is linked to dumping of mercury into the bay by a local corporation, where it enters the food chain. People who eat fish from the bay are affected with the disorder, which is caused by mercury poisoning.

Electronics

The Lip company in France produces the first commercial watch to run on electric batteries.

William Shockley, Walter Brattain, and John Bardeen of the United States win the Nobel Prize in physics for their studies on semiconductors and the invention of the electronic transistor. *See also* 1947 ELEC.

Energy

Christopher Hinton [b. Tisbury, England, May 12, 1901, d. London, June 22, 1983] opens Calder Hall in England on October 17. It is the first large-scale nuclear power plant designed for peaceful purposes, producing 4.2 megawatts of electricity. *See also* 1953 ENER; 1957 ENER.

Materials

Fiber-reactive dyes are introduced commercially for the first time. Developed primarily for artificial fibers and for

cotton, these are easy to apply at low cost and quite fast.

Medicine & health

Birth-control pills are used in a large-scale test conducted by John Rock [b. Marlborough, Massachusetts, March 24, 1890, d. New Hampshire, December 4, 1984] and Gregory Pincus [b. Woodbine, New Jersey, April 9, 1903, d. Boston, August 22, 1967] in Puerto Rico. *See also* 1951 MED; 1961 MED.

The kidney dialysis machine, developed by Wilhelm Kolff in 1943, comes into use in the United States. *See also* 1943 MED; 1964 MED.

E. Donnall Thomas [b. Mart, Texas, March 15, 1920] performs the first successful experimental bone marrow transplants on human identical twins as well as many experimental transplants on dogs. *See also* 1968 MED; 1990 MED.

Paul Maurice Zoll [b. Boston, July 15, 1911, d. Boston, January 5, 1999] finds a way to halt arrhythmia with electrical currents applied to the chest. *See also* 1947 MED; 1958 MED.

Organic chemist Frederick Charles Novello introduces the diuretic drug chlorothiazide to treat high blood pressure. *See also* 1950 MED.

Bruno Kirsh discovers peculiar dense bodies in the heart cells of guinea pigs. The function of these bodies is unknown at this time, but much later they will be discovered to release hormones that help regulate the circulatory system. *See also* 1981 MED.

Walter Hess, after developing the technique of using small

electrodes to stimulate specific regions of the brain, identifies various regions in the brain with their functions. He publishes an atlas of the brain based on his work with dogs and cats. *See also* 1876 MED.

Werner Forssmann, Dickinson W. Richards, and French-American physiologist André F. Couraud win the Nobel Prize for physiology or medicine for their use of the catheter for study of the interior of the heart and circulatory system. *See also* 1929 MED; 1940 MED.

Physics

Clyde Lorrain Cowan, Jr. [b. Detroit, Michigan, December 6, 1919, d. 1974] and Frederick Reines [b. Paterson, New Jersey, March 16, 1918, d. Orange, California, August 26, 1998] observe neutrinos for the first time (they had been predicted by Wolfgang Pauli in 1930). *See also* 1934 PHY; 1965 AST.

Chen Ning Yang and Tsung-Dao Lee [b. Shanghai, China, November 24, 1926] in May realize that conservation of parity has never been checked for the weak force. By June they have a paper proposing experiments that could be used to determine whether or not parity is conserved. *See also* 1933 PHY; 1957 PHY.

K. Lande, E.T. Booth, J. Impeduglia, and Leon M. Lederman [b. New York City, July 15, 1922] establish the existence of a long-lived neutral K particle (a.k.a. kaon) and determine its decay modes. *See also* 1955 PHY.

B. Cook, G.R. Lambertson, O. Picconi, and W.A. Wentzel discover the antineutron. *See also* 1933 PHY.

I Tools

Nicolaas Bloembergen [b. Dordrecht, Netherlands, March 11, 1920] lays the theoretical foundations for the construction of a solid-state maser (the microwave analogue of a laser) that will produce microwaves continuously instead of intermittently. *See also* 1953 TOOL.

✈ Transportation

On January 31 the air force ground-tests its first nuclear-powered jet engine — intended for a bomber. It produces mildly radioactive exhaust as well as too much direct radiation for unshielded personnel to remain near it. *See also* 1948 TRAN; 1961 TRAN.

Containerships, invented by Malcolm MacLean, are introduced for freight between U.S. ports. The first containership is the *Ideal X* out of Newark, New Jersey, bound for Houston, Texas. *See also* 1954 TRAN.

1957

★ Astronomy

Astronomer Bernard Lovell and engineer Sir Charles Husband supervise construction of a steerable 76-m (250-ft) radio telescope at Jodrell Bank, which comes into operation this year. *See also* 1946 AST; 1993 AST.

Martin Ryle suggests that changes in brightness of Seyfert galaxies are caused by the ejection of blobs of matter that travel at nearly the speed of light. *See also* 1971 AST.

↗ Biology

Mahlon Bush Hoagland [b. Boston, Massachusetts, October 5, 1921], working with protein synthesis, establishes that transfer-RNA combines with specific amino acids, following instructions from DNA. It will be later established that these acids are then combined with each other by messenger RNA. *See also* 1953 BIO; 1960 BIO.

Arthur Kornberg synthesizes DNA by the action of enzymes on nucleic-acid bases, or nucleotides. The DNA is not biologically active, however. *See also* 1956 BIO; 1959 BIO.

Sune K. Bergström [b. Stockholm, Sweden, January 10, 1916] isolates prostaglandins from sheep glands. *See also* 1982 BIO.

Melvin Calvin describes the metabolic path of carbon in photosynthesis. *See also* 1961 CHEM.

▷ Chemistry

Sir Alexander Todd of England wins the Nobel Prize in chemistry for his study of

nucleic acids. *See also* 1939 CHEM.

💻 Computers

Herbert Simon, Allen Newell, and J. Cliff Shaw develop the program GPS (General Problem Solver). It is derived from Logic Theorist and is an early form of artificial intelligence program. John McCarthy founds the Artificial Intelligence Department at MIT. *See also* 1956 COMM; 1959 COMM.

🌐 Earth science

English geophysicist Sir Edward Crisp Bullard [b. September 21, 1907, d. April 3, 1980] leads the team that develops potassium-argon dating, used for dates too young for uranium dating and too old for the carbon-14 technique. *See also* 1947 ARCH; 1983 ARCH.

🕸 Ecology & the environment

George Evelyn Hutchinson [b. Cambridge, England, January 30, 1903, d. May 17, 1991] defines the ecological niche as an abstract hypervolume in a space with axes for each of the environmental and biological variables that affect the organism whose niche it is; that is, the niche is a region both in space and in possible behaviors that the organism occupies. *See also* 1959 ECOL.

Roger Revelle [b. Seattle, Washington, March 7, 1909, d. La Jolla, California, July 15, 1991] and Hans Suess [b. Vienna, Austria, 1909, d. 1989] argue that burning fossil fuels has increased atmospheric carbon dioxide. *See also* 1958 ECOL.

Scientists establish a link between asbestos and lung cancer. *See also* 1955 ECOL.

West German workers manufacturing the herbicide 2,4,5-T develop a skin disease later named chloracne; their cases lead to the first recognition that a dioxin frequently contaminates such herbicides. *See also* 1977 ECOL.

Large amounts of nuclear waste from a Soviet defense plant explode on September 29 near Kyshtym in the Ural Mountains, contaminating 800 km² (300 sq mi) and causing some 30 towns and villages to be permanently evacuated. *See also* 1956 ECOL; 1986 ECOL.

In October stored nuclear energy in graphite, while undergoing “controlled” release at the Windscale (now Sellafield) nuclear power plant in England, gets out of hand and destroys the core of the reactor, releasing radioactivity into the environment; the British government attempts to suppress news of the accident. *See also* 1953 ENER; 1979 ECOL.

≡ Electronics

Several engineers and scientists leave Shockley Semiconductor Laboratory when William Shockley refuses to allow them to pursue research into silicon transistors. Gordon Moore [b. San Francisco, January 3, 1929], Robert Noyce [b. Burlington,



THE 76-M (250-FT) LOVELL TELESCOPE AT JODRELL BANK When the Lovell Telescope was completed in 1957 it was the largest steerable radio telescope ever built (and is still the third largest). Not only has the Lovell Telescope been at the forefront of radio astronomy, but it also has frequently been pressed into service for receipt of faint communications from satellites and space probes, starting with Sputnik I.

Iowa, December 12, 1927, d. Austin, Texas, June 3, 1990] and others of this group found Fairchild Semiconductor. *See also* 1954 ELEC; 1958 ELEC.

Energy

Prototype rotary engines designed by Felix Wankel are tested in Germany. *See also* 1929 ENER.

In October the General Electric Boiling Water Reactor, the first power reactor to be supported entirely with private money, starts producing 5000 kW of electricity for the Pacific Gas and Electric grid. *See also* 1954 ENER.

In December the Shippingport Atomic Power Station, designed and constructed in part by U.S. admiral Hyman Rickover, opens in Pennsylvania, the first commercial nuclear power plant in the United States. *See also* 1954 ENER; 1989 ENER.

Mathematics

Jaroslav Kurzweil, independently from Ralph Henstock, who had suggested a similar idea in 1955, develops the gauge integral, a general definition that is close in concept to the original Riemann integral, but with a firmer logical foundation. *See also* 1854 MATH.

Medicine & health

Polish-American microbiologist Albert Bruce Sabin [b. Bielsk, Poland, August 26, 1906, d. Washington, DC, March 3, 1993] develops a polio vaccine based on live, weakened viruses. *See also* 1952 MED.

Clarence Lillehei and Earl Bakken [b. Minneapolis, Minnesota, 1924] introduce the external pacemaker for con-

trolling heart action. *See also* 1956 MED; 1958 MED.

Gertrude Elion [b. New York City, January 23, 1918, d. Chapel Hill, North Carolina, February 21, 1999] creates the first immunosuppressant, a drug that suppresses the immune system. *See also* 1972 MED.

British virologist Alick Isaacs [b. July 17, 1921, d. January 26, 1967] and Swiss physician Jean Lindenmann discover interferons, natural substances produced by the body that fight viruses. *See also* 1980 BIO.

The high-speed dental drill is introduced, making it possible to work on teeth painlessly without anesthetics for simple fillings; it is driven by a tiny turbine powered by pressurized air. *See also* 1872 MED.

Allan MacLeod Cormack [b. Johannesburg, South Africa, February 23, 1924, d. Winchester, Massachusetts, May 7, 1998], then at the University of Capetown in South Africa, begins development of the CT scan; no one at the time seems interested. *See also* 1917 MED; 1960 MED.

Daniel Bovet of Italy wins the Nobel Prize for physiology or medicine for his discovery of antihistamines and work with curare. *See also* 1937 MED.

Physics

John Bardeen, Leon N. Cooper [b. New York City, February 28, 1930], and John Robert (Bob) Schrieffer [b. Oak Park, Illinois, May 31, 1931] formulate the “BCS theory,” which explains superconductivity by assuming the existence of coupled electrons, called Cooper pairs, that cannot undergo scattering by collisions with

atoms in the conductor. *See also* 1911 PHY.

Bruno Pontecorvo [b. Pisa, Italy, August 22, 1913, d. Dubna, Russia, September 24, 1993] first suggests, at Dubna, the existence of neutrino oscillations — under the right conditions different species of neutrinos might be able to interchange roles, an electron neutrino becoming a muon neutrino, for example. *See also* 1998 PHY.

The Columbia University Physics Department on January 15 announces that experiments conducted by Chien-Shiung Wu [b. Shanghai, China, May 31, 1912, d. New York City, February 16, 1997] based on theoretical work by Chen Ning Yang and Tsung-Dao Lee show that parity is not conserved for weak interactions (specifically the decay of cobalt-60 differentiates left from right). *See also* 1956 PHY; 1964 PHY.

Gerhart Lüders [b. 1920, d. 1995] and Wolfgang Pauli prove the CPT theorem, which states that transformation of a particle into an antiparticle leaves the laws of physics intact as long as charge, parity, and time are all reversed (that is, positive becomes negative, right becomes left, and past becomes future, or vice versa). *See also* 1937 PHY.

Leo Esaki [b. Osaka, Japan, March 12, 1925] discovers that electrons are able to tunnel from one region of a semiconductor to another, bypassing what would ordinarily be a barrier and causing resistance to decrease with increasing current instead of increasing, as would be expected. *See also* 1928 PHY; 1973 PHY.

In November Julian

Schwinger makes the first suggestion that weak interactions are mediated by charged vector bosons, later called W particles. The massive W particles will finally be detected by Carlo Rubbia. *See also* 1933 PHY; 1983 PHY.

In experiments conducted since 1954, Robert Hofstadter [b. New York City, February 5, 1915, d. Stanford, California, November 17, 1990] discovers that protons and neutrons have a structure. He interprets this as a positive central core surrounded by two shells of mesons, with one of the shells in the neutron being sufficiently negative to make the particle neutral. *See also* 1961 PHY.

Princeton graduate student Hugh Everett III proposes that quantum theory predicts that anytime a choice is made, the universe splits into two separate universes, one for each branch of the choice. All such universes actually exist, but cannot be in touch with each other after they separate.

Tsung-Dao Lee and Chen Ning Yang of China win the 1957 Nobel Prize for physics for their discovery of violations of the law of conservation of parity. *See also* 1956 PHY.

Tools

Columbia University physics graduate Gordon Gould [b. New York City, July 17, 1920] on November 11 has the idea that will translate into the laser; Gould does not, however, apply for a patent until 1959 and by then others have also begun to work on lasers. Gould's patent claims are not to be accepted until after 1986. *See also* 1953 TOOL; 1958 TOOL.

God is left-handed

After World War II, physicists in the United States and elsewhere were able to return to basic research. One group used balloons and other devices to lift photographic emulsions high in the atmosphere, where they recorded cosmic-ray tracks. Cosmic rays include the particles that bombard Earth from space and also the particles that these primary particles knock out of the molecules that they encounter in the atmosphere. Collisions between a cosmic ray and a molecule produce higher energies than the particle accelerators ("atom smashers") of the day were able to achieve. As Albert Einstein had shown in 1905, energy can be changed into mass. In fact, one result of these collisions at high energies is the production of new particles of masses greater than any observed in ordinary matter.

The new particles often behaved in very strange ways. In fact, Murray Gell-Mann, in the early 1950s, began to call one particular property *strangeness*, a name that has stuck. As a result, in physics (unlike ordinary life), it is possible to specify completely whether something is "strange" or not. Among the strangest of the strange were certain particles that have undergone numerous name changes. These particles are the neutral K (kappa) mesons, also called kaons. In the 1950s, physicists called one variety of K meson tau and another theta (today tau refers to an entirely different particle). The problem with tau and theta was that every bit of evidence suggested that they should be exactly the same particle; but when, like all heavy particles, they decayed into lighter particles, tau decayed into three particles and theta decayed into two. Furthermore, the products of the two decays implied that the original particles had to be different in an essential property called parity. The fundamental wisdom of the time was that two otherwise identical particles could not have unequal parities.

Parity itself is a simple concept that is based on an either/or situation. The most common representations are in terms of numbers, usually +1 and -1, or in terms of right and left. Since these two seemingly dissimilar ideas are mathematically identical, physicists often use the numbers +1 and -1, even when the actual physical operation is closer to right and left. Parity for particles is an example of this. The tau has a parity of -1 while the theta has a parity of +1. The experiment that finally explained "the tau-theta paradox," however, rested on the difference between right and left.

By 1956 the tau-theta problem was a focal session for a physics conference in Rochester, New York. Physicists Martin Block and Richard Feynman were roommates at the meeting. Block suggested a radical idea to Feynman, which Feynman passed on to the conferees at the session on the tau-theta problem. Block's idea was that there is some fundamental difference between right and left. This was radical because the idea that right and left are

essentially the same, a concept called the law of conservation of parity, was one of the pillars of theoretical physics at the time. Chen Ning Yang, one of the speakers at that session, and T.D. Lee met a month later at the White Rose Cafe near Columbia University and decided to work out the implications of Block's idea. In another month or so Yang and Lee were able to point to specific experiments that would resolve the question. Since they were theoreticians, others performed the experiments. By the end of the year, experiments conducted under the leadership of Chien-Shiung Wu had shown that parity is not conserved in interactions that involve the weak interaction, one of the fundamental forces of nature. Specifically, cobalt-60, whose atoms decay as a result of the weak interaction, preferentially decays toward the left, not the right.

The announcement of these results in January 1957 forced a major revision in the ideas of physicists concerning weak interactions. It was a revolution whose implications are not completely resolved today. Wolfgang Pauli captured the idea best in a phrase calling God "a weak left-hander!" He initially used those words to dismiss the results, and did not accept the fall of parity until he read papers produced by physicists who confirmed Wu's result in various other experiments.

This lack of symmetry in a world dominated by symmetry may be necessary for the universe to exist at all. In most reactions, matter and its exact opposite, antimatter, are produced in equal amounts. Yet the existing universe, as far as we can tell, contains matter and not antimatter. Matter and antimatter interact to destroy each other whenever they meet. If equal amounts of matter and antimatter were produced in the creation of the universe, this reaction would have "uncreated" it. Physicists think that some asymmetrical reaction at the beginning of time must have prevented this from happening, or we would not be here to think about it.

About the same time as conservation of parity was being overthrown, theoreticians established the CPT theorem, the essence of which is that any interaction between particles must remain the same if you change the charge of all the particles (for example, an electron becomes changed to a positron), if you change all the parities (for example, right becomes left), and if you switch time from running forward to running backward. This theorem derives from fundamental principles and no one doubts that it is true. Thus, when in 1964 physicists demonstrated that changing both the charge and parity changes some interactions, it became clear that some particle interactions must be different when run backward in time from when run forward. In 1998 such interactions were finally found. No one made time flow backward, but changing the sequence of events so that the last event of one sequence was used for the first event of another produced a reverse sequence different from the forward version. Before this all such interchanges with the beginning events reversed produced the same sequence, but in reverse.

Nikolay Gennadiyevich Basov [b. Usman, Russia, December 14, 1922, d. June 30, 2001] develops molecular oscillators that operate in the optical range, an important precursor of the laser. *See also* 1964 PHY.

Soviet physicist Aleksandr Prokhorov [b. Atherton, Australia, July 11, 1916, d. Moscow, January 8, 2002] studies the spectrum of light produced by the ruby. This leads to the suggestion of using a ruby to build a laser (which will be the medium employed in the first laser in 1960). *See also* 1964 PHY.

The U.S. Atomic Energy Commission begins Project Plowshare, officially the Division of Peaceful Nuclear Explosives. Various plans are developed for using nuclear explosions to create harbors, improve mines, and so forth. Because of the dangers of nuclear contamination, very few of these plans are carried out. *See also* 1954 TOOL; 1967 TOOL.

→ Transportation

The Semyorka intercontinental ballistic missile, designed by Sergei Korolev [b. Zhitomir, Russia, December 30, 1906, d. January 14, 1966], is adapted to launch *Sputnik* satellites. The first artificial satellite, *Sputnik 1*, is launched by the Soviet Union on October 4; it is about 58 cm (23 in.) in diameter and weighs about 84 kg (184 lb); *Sputnik 2* is launched on November 3, carrying the live dog Laika into space (but not bringing her back). Laika lives for ten days, showing that life can survive aboard spacecraft. *See also* 1687 TRAN.

The U.S. Transportation Department orders air bags

for all new U.S. cars to be installed by the 1975 model year (later changed to 1977). *See also* 1953 TRAN.

1958

◀ Anthropology

Workers find evidence of Europe's oldest building, a 500,000-year-old hunting lodge that once sat on the Mediterranean coast near Nice, France — now, some 20 m (70 ft) higher than sea level on a hill known as Terra Amata. *See also* 400,000 BCE CONS.

★ Astronomy

Soviet astronomer Nikolai Alexandrovich Kozyrev [b. St. Petersburg, Soviet Union (Russia), 1908, d. 1983], from the Crimean Astrophysical Observatory in the Soviet Union, observes a cloud, apparently of carbon particles, in the crater Alphonsus on the Moon, one of the few observations from Earth to show any change whatsoever on the Moon. It is described as a "red event" and thought to be volcanic activity. Slightly more than a decade later, however, the possibility of lunar volcanism will be rejected after people who visit the Moon observe no geological activity. The red event may have been a meteorite impact.

American physicist Eugene Newman Parker [b. Houghton, Michigan, June 10, 1927] demonstrates that there is a "solar wind" of particles thrown out by the Sun. It is this solar wind that makes comets' tails point away from the Sun. *See also* 1540 AST.

↗ Biology

Russian herpetologist Ilya

Darevsky discovers some species of lizards in Soviet Armenia consist entirely of females who reproduce parthenogenetically — without fertilization by males; this is the first known example of all-female vertebrate species.

Sidney Walter Fox, American biochemist [b. Los Angeles, March 24, 1912, d. August 10, 1998] performs experiments that show that life might have originated when intense heat caused amino acids to form polymers that become tiny spheres when dissolved in water. *See also* 1953 BIO.

Edward O. Wilson discovers that ants communicate through compounds he calls "chemical releasers," which will be named pheromones by Adolf Butenandt. *See also* 1919 BIO.

George Beadle, Edward Tatum, and Joshua Lederberg of the United States share the Nobel Prize for physiology or medicine, Beadle and Tatum for relating genes to enzymes and Lederberg for genetic recombination. *See also* 1941 BIO; 1952 BIO.

▷ Chemistry

Stanford Moore [b. Chicago, Illinois, September 4, 1913, d. New York City, August 23, 1982] and William H. Stein [b. New York City, June 25, 1911, d. New York, New York, February 2, 1980] invent a device that automatically analyzes the amino acids in proteins. *See also* 1959 CHEM.

Frederick Sanger of England wins the Nobel Prize in chemistry for his discovery of the structure of insulin. *See also* 1954 MED.



Edward Osborne Wilson
[b. Birmingham, Alabama, June 10, 1929]

Wilson first distinguished himself by becoming the world's leading authority on ants. His discoveries included the finding that ants communicate primarily through pheromones. Wilson then became the principal proponent of sociobiology; his belief that there is a biological basis for the social behavior of all animals, including humans, has aroused much controversy. Wilson also has been a major voice in efforts to maintain Earth's biodiversity.

◀ Communication

Stereo records are introduced commercially; in the system that becomes the standard, each sound channel is engraved on one side of a single groove. Earlier systems sometimes used two separate grooves. Duke Ellington experimented with stereo recording much earlier, but the results were originally released as monaural recordings. *See also* 1931 COMM; 1961 COMM.

Bell introduces the modem dataphone which allows the use of ordinary telephone lines for transmitting binary data. *See also* 1955 COMM.

On December 18 *Score*, sometimes considered the first communications satellite, is launched by the U.S. army. It transmits from orbit a message prerecorded by President Eisenhower to listeners on Earth. *See also* 1960 COMM.

The space race

In 1957 science watchers were excited by the first major program of worldwide scientific cooperation, the International Geophysical Year (IGY), a two-year study of Earth and its environment in space. In the West, articles about the program sometimes mentioned that as part of the effort, the United States would launch an artificial satellite. Few noted that the Soviet Union also planned such a launch, possibly because they doubted that this achievement was within Soviet technological capabilities.

The physics involved in putting a satellite into orbit about Earth had been known since Isaac Newton's time. Indeed, Newton was the first to suggest that an artificial satellite was possible. All that was required to launch a satellite was a rocket of sufficient power. Both the United States and the Soviet Union had taken German rocket engineers captive near the end of World War II. These engineers had since been employed in each country, along with other scientists, in developing large rockets that could travel great distances.

U.S. scientists and the public around the world were astonished when the Soviet Union became the first to succeed in putting a satellite in orbit. People all over the world who had previously shown little interest in the IGY satellite program became very excited by *Sputnik 1* (sometimes translated as "fellow traveler 1"). When U.S. launch efforts at first failed, many developed a new respect for Soviet technology. Ultimately, the United States turned to its German rocket scientists for success, as the Soviet Union had also done.

From the beginning of the Space Age in October 1957, the Soviet Union and the United States took two different approaches to solving technological problems. The Soviet way was called brute force, because it relied on powerful rockets. Early U.S. rockets, except for close imitations of German V-2 rockets, were unre-

liable and not so powerful. The Soviet approach was the clear winner at first. The Soviets not only launched the first satellite but also, in 1959, the first probe to approach the Moon and go into orbit about the Sun. Three U.S. attempts in 1958 to get to the Moon failed, but U.S. scientists came close about two months after the Russians. Soon after that, a Soviet rocket actually hit the Moon, and another went into orbit about it.

The space race was closely watched all over Earth. In the early 1960s, the immediate goal was to put a human into orbit. With their more powerful rockets, the Russians won that round as well. It was nearly a year after cosmonaut Yuri Gagarin made the original one-orbit flight that astronaut (later senator) John Glenn duplicated the feat. Before that, on March 25, 1961, U.S. President John F. Kennedy tried to shift the focus of the race. He made it a national goal to put humans on the Moon by the end of the decade.

For most observers, human spaceflight seemed to be all that mattered in the race. When the United States in 1962 became the first nation to succeed in having a probe reach another planet (*Mariner 2* reaches the vicinity of Venus after unsuccessful tries by both contenders), no one took that to mean that the United States had leaped in front in the race.

But, as a skilled boxer wears down a puncher, the United States steadily piled up points with the judges. When in 1969 the first astronauts set foot on the Moon, Kennedy's strategy proved correct. By landing humans on the Moon, the United States had won in the eyes of the world. The Soviet Union did not even try to duplicate the feat, but instead worked toward the development of a long-duration space station. This was successful, although not much noted at first in the United States, where the emphasis was primarily on the space shuttle missions. The space race did not end until the cold war did, as the Soviet Union disintegrated. Then the United States and Russia began to work together on the International Space Station instead of competing in space.

Inspired by a science fiction story, Yuri Denisyuk in Russia re-invents holography, creating an improved form now known as a volume-reflection hologram (or a Denisyuk hologram). It is the first hologram that can be viewed in white light. Skepticism in the Soviet Union will prevent publication of the idea until 1962. *See also* 1955 COMM; 1960 COMM.

William A. Higinbotham [b. Bridgeport, Connecticut,

1910, d. Gainesville, Georgia, November 10, 1994], a physicist specializing in electronic systems, develops the first video game, a tennis game similar to the game Pong (developed 15 years later), for a public show of science at Brookhaven National Laboratory on Long Island, New York. *See also* 1972 COMM.

Computer language ALGOL 58 is introduced at an international conference in Zurich;

ALGOL stands for Algorithmic Language.

Computers

The first known use of the word *software* is in an article by John Tukey in the January *American Mathematical Monthly*. *See also* 1948 COMP.

Alex Bernstein and Michael Roberts develop a chess program that runs on an IBM 704 and plays like a fair amateur. *See also* 1956 COMM.

RCA launches the BIZMAC computer. It can access 200 magnetic tapes via a network of smaller computers and is used for the storing and processing of large data bases. *See also* 1956 COMP; 1970 COMP.

Construction

Ludwig Mies van der Rohe [b. Aachen, Germany, March 27, 1886, d. Chicago, Illinois, August 17, 1969] designs the Seagram Building in New York City with bronze walls

and tinted glass curtain-wall construction; it becomes the prototype of office building construction in the 1960s and 1970s. *See also* 1918 CONS.

Earth science

On January 31 the United States launches its first satellite and first of the *Explorer* series aboard a Jupiter C rocket. When radiation counters aboard U.S. satellites *Explorer I* and *III* mysteriously fail, James Van Allen suspects the cause is high levels of radiation. He designs a better radiation counter for *Explorer IV*, launched July 26, which results in the discovery of the radiation belt that surrounds Earth. *See also* 1957 TRAN; 1962 EAR.

John Aloysius O'Keefe [b. Lynn, Massachusetts, October 13, 1916, d. Sioux Falls, South Dakota, September 8, 2000] uses the orbit of the *U.S. Vanguard* satellite, launched on March 17, 1958, to show that Earth is slightly pear-shaped with a bulge of about 15 m (50 ft) in the Southern Hemisphere. *See also* 1672 EAR; 1962 EAR.

As other geophysicists had proposed, Arvid Herzenberg develops a possible way that a “dynamo” of liquid iron in motion inside Earth could create the observed magnetic field. He suggests that there could be two separate rotating spheres in the outer core.

Ecology & the environment

Canadian-American Robert Helmer MacArthur [b. April 7, 1930, d. November 1, 1972] begins observations that lead to his discovery of warbler feeding zones in spruce forests. *See also* 1967 ECOL.

At Roger Revelle's urging, the

first modern carbon dioxide monitoring program to accurately record atmospheric CO₂ levels begins atop Mauna Loa in Hawaii. *See also* 1957 ECOL.

Electronics

Jack St. Clair Kilby [b. Jefferson City, Missouri, November 8, 1923] of Texas Instruments Inc. and Robert Noyce of the Fairchild Semiconductor Corporation separately invent the integrated circuit, a device that carries several electronic components on one silicon chip. Kilby demonstrates the first; it contains a few transistors and capacitors consisting of p-n junctions on a single support of silicon. The circuit is a simple oscillator and proves that circuits made of semiconductor junctions on a single chip are feasible. Integrated circuits will in a few years become the main components of computers. *See also* 1951 ELEC; 1970 ELEC.

Materials

Kaiser Aluminum introduces the first aluminum cans; previous cans had been made from steel plated with tin. *See also* 1886 MATR; 1965 MATR.

James Fergason [b. Wakenda, Missouri, January 12, 1934] of Westinghouse Electric develops the first application of liquid crystals, a coating that changes color depending on temperature. This eventually will be used to map warm or cool spots on humans for medical purposes. *See also* 1889 CHEM; 1971 MATR.

Medicine & health

Italian-American virologist Renato Dulbecco [b. Cannizzaro, Italy, February 22, 1914] begins studying the relation between polyoma virus and

other viruses that cause cancer and the tumors they produce. He discovers that such viruses cause cancer by inserting their own DNA into the chromosomes of cells. *See also* 1975 BIO.

On October 8 Ake Senning [b. Rattvik, Sweden, September 14, 1915, d. 2000] and other surgeons in Stockholm, Sweden, install the first implantable heartbeat pacemaker in Arne Larsson [b. 1916, d. Saltsjö-Duvnäs, Sweden, December 28, 2001], successfully treating his Stoke-Adams syndrome, a heart block condition. *See also* 1957 MED; 1960 MED.

Bifocal contact lenses are introduced. *See also* 1948 MED; 1965 MED.

Glasgow obstetrician and professor of midwifery at the University of Glasgow Ian Donald [b. Cornwall, Scotland, December 1910, d. June 19, 1987] describes in *Lancet* the use of ultrasound to examine unborn children based on studies he and colleagues have been making since 1957. It is this paper that inaugurates the routine use of ultrasound during pregnancy. *See also* 1952 MED.

Physics

Physicists show that charge conjugation is not preserved in some interactions; that is, when all positive charges are replaced by negative charges and vice versa, a different reaction occurs; this is closely related to the breakdown of conservation of parity. *See also* 1957 PHY.

The Casimir force between two sufficiently close plates, caused by particles arising and vanishing in a vacuum, is observed experimentally. *See also* 1948 PHY.

Lev Landau completes a study of the behavior of liquid helium-3, which acts partly as a Fermi condensate. His previous study of liquid helium-4, conducted between 1941 and 1947, showed it to be a Bose-Einstein condensate (BEC). *See also* 1962 PHY.

Kai M. Siegbahn [b. Lund, Sweden, April 20, 1918] develops electron spectroscopy for chemical analysis (ESCA) using X-ray ionization sources. *See also* 1981 PHY.

Pavel A. Cherenkov, Ilya M. Frank, and Igor Tamm of the Soviet Union win the Nobel Prize for physics for discovery of the principle of light emission by electrically charged particles moving faster than the speed of light in a medium. *See also* 1934 PHY; 1937 PHY.

Tools

American physicists Arthur L. Schawlow [b. Mount Vernon, New York, May 5, 1921, d. Palo Alto, California, April 28, 1999] and Charles Townes show theoretically that the principle of the maser can be applied to produce and amplify visible light in a device called a laser (short for light amplification by stimulated emission of radiation). The first working laser is built in 1960. *See also* 1953 TOOL; 1960 TOOL.

1959

Anthropology

English anthropologist Louis Leakey and his wife Mary Leakey find fossil remains of an early hominid from about 1,750,000 years ago that the Leakeys name *Zinjanthropus*, sometimes known as Nutcracker Man from the large teeth. Later anthropologists usually

refer to the species as *Australopithecus boisei* or as *Paranthropus boisei*.

▲ Archaeology

A. Leo Oppenheim [b. Vienna, Austria, June 7, 1904, d. July 21, 1974] analyzes a clay envelope found at Nuzi, north of Babylon, in 1920. It is inscribed with a list of various kinds of sheep, 49 in all, Inside the envelope had been 49 counters or tokens (lost by Oppenheim's time); Oppenheim uses this and other evidence to propose that that the tokens had been an accounting system for sheep, just as some peasants today keep track of their sheep with small stones. *See also* 3500 BCE COMM; 1972 COMM.

★ Astronomy

On April 7 Czech astronomer Zdenek Ceplecha, founder of the European Fireball Network, observes a fireball from his home. His network is able to trace the fireball to where it falls on Earth near Příbram (the Czech Republic). Only 6.8 kg (15 lb) remains of what was once a one-ton visitor from the asteroid belt. It is the first meteorite ever to be tracked as a fireball back to its original orbit between Mars and Jupiter. *See also* 1970 AST.

Radar contact is made with the Sun by Von R. Eshleman at the Stanford Research Institute in the United States. *See also* 1945 AST.

The Soviet Union launches *Lunik I* on January 2. Aimed at the Moon, it misses and goes into orbit around the Sun, where it is widely hailed as the first artificial planet and renamed *Mechta* ("dream"). Space probe *Lunik II*, launched September 9, becomes the first human-produced object to reach the Moon's surface when it crash-lands on September 14. On October 4 the Soviet Union launches *Lunik III*; its path takes it past the Moon in such a way that it can return photographs of the far side to Earth, the first views people have ever had of the far side of the Moon. *See also* 1957 TRAN; 1961 TRAN.

The first U.S. space probe aimed at the Moon, *Pioneer 4*, is launched on March 3; it misses and goes into orbit about the Sun.

❖ Biology

Japanese scientists discover that resistance to antibodies in the bacterium *Shigella dysenteriae* is carried from one bacterium to another by plas-

mids, small circles of DNA that are found in most bacteria in addition to the chromosomes. *See also* 1952 BIO; 1964 BIO.

Gerald M. Edelman [b. New York City, July 1, 1929] and coworkers at Rockefeller University construct a precise model of an entire molecule of an antibody. The antibody is a four-chain protein consisting of more than 1300 amino acids. Edelman and his team also identify the locations on the molecule where binding to an antigen occurs. *See also* 1972 BIO.

Severo Ochoa and Arthur Kornberg of the United States win the Nobel Prize for physiology or medicine for the artificial production of nucleic acids with enzymes. *See also* 1955 BIO; 1957 BIO.

▷ Chemistry

German-Canadian physicist Gerhard Herzberg [b. Hamburg, Germany, December 25, 1904, d. Ottawa, Canada, March 3, 1999] makes a spectroscopic analysis of the extremely short-lived CH₂ free radical (methylene), a key step in establishing the theory of the internal structure and energy states of molecules in general. *See also* 1971 CHEM.

Stanford Moore and William H. Stein use their automatic amino acid analyzer to determine the complete chemical structure of ribonuclease, the first such analysis of an enzyme. *See also* 1958 CHEM; 1972 CHEM.

The Molecular Basis of Evolution by Christian Bohrmer Anfinsen [b. Monessen, Pennsylvania, March 26, 1916, d. Randallstown, Maryland, May 14, 1995] is based on Anfinsen's work with the structure and function of enzymes. *See also* 1972 CHEM.

Jaroslav Heyrovský of Czechoslovakia (Czech Republic) wins the Nobel Prize in chemistry for his polarography for electrochemical analysis. *See also* 1922 CHEM.

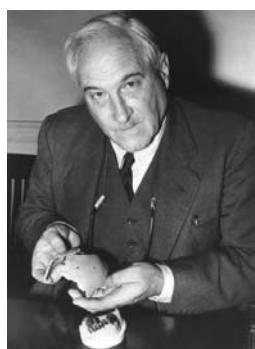
☛ Communication

The first commercial Xerox® copier is introduced. *See also* 1947 COMM.

Novelist and scientist C.P. (Charles Percy) Snow [b. London, October 15, 1905, d. Leicester, England, July 1, 1980] speaks of "The Two Cultures and the Scientific Revolution" at Cambridge University, England, in May, noting a growing communications gap between those who understand and are concerned with science and those who focus solely on the arts.

John McCarthy completes the first version of LISP (List Processing), a programming language especially designed for applications in artificial intelligence. *See also* 1956 COMM.

Grace Hopper and Charles A. Phillips [b. 1906, d. 1985] invent COBOL, the Common Business Orientated Language, a computer language designed



Louis Seymour Bazett Leakey

[b. Kabete, Kenya, August 7, 1903, d. London, October 1, 1972]

Leakey pioneered paleoanthropology in East Africa, discovering several important ape fossils and the Oldowan tool industry. He led his entire family into paleoanthropology. In 1960 he described the first specimen of *Homo habilis* (the fossil cranium was found by his son Jonathan). His wife, Mary Nicol Leakey [b. London, February 6, 1913, d. December 9, 1996], found the first specimen of *Paranthropus boisei* in 1959 and led the expedition that found australopithecine footprints at Laetoli, Tanzania. Their son Richard Leakey found the first fossil of *Homo ergaster* in 1984. Richard's wife Meave Leakey was in 1994 a codiscoverer of *Australopithecus anamensis* and in 2001 found *Kenyanthropus platyops*. In addition to starting the members of his family on careers in anthropology, he also influenced primatology by recruiting Jane Goodall and others to the field.

for business uses that becomes the most widely used language for that purpose. *See also* 1956 COMM; 1960 COMM.

Computers

IBM builds the 8090 Data Processing System for the U.S. air force to use as the computer for the Ballistic Missile Early Warning System.

Earth science

The U.S. Weather Bureau institutes the temperature-humidity index (THI) as a better way of judging how uncomfortable a hot summer day is. *See also* 2001 EAR.

Alvin Van Valkenburg [b. 1913, d. 1991] and Charles Weir, both of the U.S. National Bureau of Standards, develop the first diamond-anvil pressure cell, a simple tool that revolutionizes Earth science by making it possible to duplicate the interior pressure of Earth in small laboratory samples.

The Antarctic Treaty is signed; signatories, including the United States and the Soviet Union, promise to keep the continent free from military activities and to use it for scientific research. *See also* 1820 EAR.

The U.S. *Explorer 6* satellite takes the first images of Earth as seen from space and relays them via television to stations on the ground.

Ecology & the environment

George Evelyn Hutchinson's "Homage to Santa Rosalia, or Why Are There So Many Kinds of Animals?" points out that two different species cannot occupy the same ecological niche and also that similar

species with similar niches occur in sizes that are about 1.3 times apart in all linear dimensions. *See also* 1957 ECOL.

A Norwegian fishing inspector reports that fish populations are declining in lakes with acid water. *See also* 1961 ECOL.

Electronics

Jean Hoerni [b. Geneva, Switzerland, September 26, 1924, d. 1997], at Fairchild Semiconductors, produces a "flat," or planar, transistor in which the transistor junctions are insulated with silicon. After Robert Noyce uses this technique to produce an integrated circuit, it will become the main method used for integrated circuits. *See also* 1958 ELEC. 1961 ELEC.

Energy

The Eveready Company introduces the first alkaline dry-cell battery, developed by Lew Urry. Using a base instead of an acid produces a zinc-carbon battery that lasts as much as five to eight times as long as the original zinc-carbon type. *See also* 1908 ENER.

Francis Thomas Bacon [b. Bilericay, England, 1904, d. 1992] builds a fuel cell in which hydrogen and oxygen react in a mixture of potassium hydroxide in water. *See also* 1839 ENER; 1965 ENER.

Medicine & health

Canadian geneticist Murray Llewellyn Barr [b. Belmont, Ontario, June 20, 1908, d. London, Ontario, May 4, 1995] discovers that one of the X chromosomes of the female forms a dark spot when a cell not undergoing mitosis is stained. The dark

spot is called a Barr body. Apparently the other X chromosome is diffuse throughout the cell, while the Barr body is coiled up tightly.

French geneticist Jerome Lejeune [b. March 17, 1925, d. April 3, 1994] determines the genetic cause of Down's syndrome: the presence of a third copy of chromosome 21. Patricia A. Jacobs and J.A. Strong show that Klinefelter's syndrome is caused by a sex-chromosome defect, an extra X chromosome (XXY). C.E. Ford shows that Turner's syndrome is a sex-chromosome defect, caused when there is only one functional X chromosome. *See also* 1954 BIO.

Norman J. Holter [b. Helena, Montana, February 1, 1914, d. 1983] introduces a portable electrocardiograph (Holter monitor) for continuous recording of an electrocardiogram to study heart patients. *See also* 1903 MED.

Physics

Lyman J. Briggs [b. Assyria, Michigan, May 7, 1974, d. March 25, 1963] shows definite evidence that a curve in baseball actually curves sideways and/or downward. He uses an array of cameras to record the flight path and examines the effect in smoke tunnels as well.

Emilio Segrè and Owen Chamberlain of the United States win the Nobel Prize for physics for their demonstration of the existence of the antiproton. *See also* 1955 PHY.

Tools

On December 29 Richard Feynman, at the annual meeting of the American Physical Society, gives a talk, "There's

Plenty of Room at the Bottom," in which he proposes etching or evaporating materials to make tiny transistors and connections, using light or electrons to create transistors, developing structures built one atom at a time, and building circuits with as few as seven atoms. Although most listeners do not expect these devices ever to come into being, virtually all Feynman's ideas will be successfully embodied over the next 30 years or so. *See also* 1987 TOOL.

Transportation

The St. Lawrence Seaway is opened on June 26, connecting the St. Lawrence River and the Great Lakes for oceangoing ships. Some of the passage is an enlargement of the first St. Lawrence Seaway, built by the Canadians in 1803, which was only 4.25 m (14 ft) deep; the new seaway is 8.23 m (27 ft) deep.

Christopher Cockerell builds and tests his first practical hovercraft, the SR N1. *See also* 1955 TRAN; 1968 TRAN.

Lenin, the first nuclear-powered icebreaker built by the Soviet Union, is commissioned.

British industrialist Hugh Kremer sets up a prize of 50,000 pounds for successful human-powered flight over a prescribed course 1.6 km (1 mi) long in the shape of a figure 8. *See also* 1977 TRAN.

1960

Anthropology

In October Jane Goodall observes tool-making by a chimpanzee, calling the attention of science to the practice. She sees a chimp that she has

named David Graybeard take a blade of grass and shape it so that it can be poked into a termite mound for the purpose of removing termites. David proceeds to eat the termites so obtained. *See also* 1960 BIO; 1996 BIO.

On October 4 Jonathan Leakey, son of Louis Leakey and Mary Leakey, finds the first recognized fossil remains of *Homo habilis*, or "Handy Man," the earliest known human, dating from as early as 2,000,000 BCE. Another member of the Leakey team, Heslon Mukiri, had discovered two teeth from *H. habilis* in 1959, but they were not recognized as from a newly found species. The species name comes from simple pebble tools that are found at the same site, although it is not established that *H. habilis* was their manufacturer. *See also* 1959 ANTH; 1996 ANTH.

■ Archaeology

George Bass heads a team of underwater archaeologists who determine that a wreck on the sea bottom near Cape Gelidonya, Turkey, is that of the oldest ship found to that date, a small freighter loaded with copper and bronze from about 1200 BCE. *See also* 1952 ARCH.

Vernon L. Scarborough and Gary V. Gallopin, studying site maps of the Tikal ruins in Guatemala, recognize that most of the construction is arranged to divert water to a series of connected canals.

Helge Ingstad [b. Bergen, Norway, December 30, 1899, d. Oslo, Norway, March 28, 2001] and Anne Stine Ingstad discover the site of the only known Norse or Viking settlement in North America (excluding Greenland) at L'Anse-aux-Meadows, Newfoundland, Canada. Proof of their discovery comes with excavations of the eight large houses at the site over the period 1961–68.

★ Astronomy

The aperture synthesis method, which applies the concept of interferometry to radio telescopes using the motion of Earth in its orbit, is introduced by Martin Ryle and Anthony Hewish [b. Fowey, England, May 11, 1924]. *See also* 1955 AST; 1974 AST.

Allan Rex Sandage [b. Iowa City, Iowa, June 18, 1926] discovers a starlike object of 16th magnitude that emits radio waves. This object, 3C 48, is later identified as a quasar when its great distance is

determined. Quasars emit vast amounts of energy, but appear in telescopes as ordinary stars.

Frank Donal Drake [b. Chicago, Illinois, May 28, 1930] runs project Ozma, a 400-hour attempt to find extraterrestrial life in the universe. The project does not find any.

❖ Biology

Kenneth Norris [b. Los Angeles, August 11, 1924, d. San Francisco, August 16, 1998] and John Prescott [b. 1935, d. Weston, Massachusetts, June 30, 1998] establish that the bottlenose dolphin uses echolocation (essentially sonar) to locate objects in water, just as bats use echolocation to locate objects in air.

Jane Goodall observes meat-eating in chimpanzees, previously believed to have been vegetarians. Periodically male chimpanzees hunt and kill a monkey, whose meat they then share with the rest of the band. *See also* 1960 ANTH.

James Bonner discovers that chromosomes synthesize RNA. *See also* 1955 BIO.

Jacques Monod [b. Paris, February 9, 1910, d. Cannes, France, May 31, 1976] and François Jacob [b. Nancy, France, June 17, 1920] mail their proof that messenger

RNA exists to the *Journal of Molecular Biology* on December 24. *See also* 1955 BIO; 1965 BIO.

The major writings on how the ear translates sound waves to the nerves by Georg von Békésy [b. Budapest, June 3, 1899, d. Hawaii, June 13, 1972], which were published over a 30-year period, are republished in a single volume as *Experiments in Hearing*. Von Békésy establishes a new theory of hearing based on the waves formed by fluid in the cochlea, which replaces a theory put forward by Hermann von Helmholtz. *See also* 1961 BIO.

Lyman Creighton Craig [b. Palmyra, Iowa, June 12, 1906, d. Glen Rock, New Jersey, July 1974] succeeds in purifying the hormone parathormone from the parathyroid gland. *See also* 1926 BIO.

□ Chemistry

Using the technique of adding a heavy atom, such as gold, to an organic molecule, Max Perutz determines the atom-by-atom structure of hemoglobin. John Cowdery Kendrew [b. Oxford, England, March 24, 1917, d. Cambridge, England, August 23, 1997] locates all of the atoms in the organic molecule myoglobin, a close relative to hemoglobin. *See also* 1953 BIO; 1962 CHEM.

Manfred Eigen [b. Bochum, Germany, May 9, 1927], who has been studying chemical reactions at time intervals as small as a nanosecond for nearly ten years, noting that the reactions often take place in a series of relaxations, determines the steps involved in acid-base catalysis and veri-



Jane Goodall

[b. London, April 3, 1934]

Goodall is best known for her long-term observations of chimpanzees in their natural habitat, particularly at the Gombe Stream Research Center in Tanzania. She has stressed that chimpanzees — humans' closest living relatives — resemble humans not only genetically and physiologically but also behaviorally. For example, chimpanzees use such gestures as kissing, tickling, embracing, holding hands, and patting one another on the back. Goodall discovered that chimpanzees use twigs and other tools to capture termites, and that they are not strict vegetarians, as had been believed.

fies the general theory explaining this. *See also* 1967 CHEM.

Charles J. Pedersen [b. Pusan, Korea, October 3, 1904, d. Salem, New Jersey, October 26, 1989] discovers the first crown ether (named so because the molecular model resembles a crown, and it is also able to crown and uncrown cations without physical damage to them). *See also* 1987 CHEM.

Willard Libby of the United States wins the Nobel Prize in chemistry for the invention of radiocarbon dating. *See also* 1947 ARCH.

Communication

Echo, the first passive communications satellite, is launched on August 12 as a result of efforts by John Pierce. *See also* 1954 TRAN; 1962 COMM.

Other communications-satellite developments are by the U.S. military. On May 22 *Midas 2*, the first U.S. spy satellite designed for detecting missile launches, relays information it obtains with infrared cameras to Earth. On August 18 the military satellite *Corona*, publicly known by the civilian code name *Discoverer 13*, is launched. It successfully returns a capsule to Earth — the first object ever returned from space. A week later *Discoverer 14* uses cameras designed by Edwin Land to spy on the Soviet Union, parachuting canisters of film back to Earth, where they are captured in air by specially equipped aircraft. They are said to yield more images in a single day than the U-2 spy system had in its entire lifetime. There will be more than a hundred similar missions in

the Corona program, which continues until 1972.

The Royal McBee Corporation develops the first automatic typewriter that punches a paper tape automatically while the original document is being typed, eliminating the need for separate tape punching. *See also* 1927 COMM; 1964 COMM.

Max V. Mathews [b. Columbus, Nebraska, November 13, 1926] of Bell writes the first music synthesizer program, MUSIC. *See also* 1969 COMM.

The International Standard, called SI after its French name, *Système International*, replaces the metric system. The International Bureau of Weights and Measures defines the standard meter as a certain multiple of the wavelength of the light emitted when krypton gas is heated. *See also* 1827 COMM; 1983 COMM.

The Census in the United States uses a Film Optical Sensing Device for Input to Computers (FOSDIC) to enter results for data processing from microfilmed Census schedules. *See also* 1890 COMP.

Paul Baran [b. Grodno, Poland, April 29, 1926] of the Rand Corporation develops the principle of packet switching, a way of interchanging data between computers that uses discrete bundles of information for each interchange. *See also* 1964 COMM.

Computers

In November Digital Equipment Corporation led by Kenneth Olsen introduces the PDP-1, a computer with a maximum memory of 26,000 bytes, making it state of the

art. It is the first commercial computer with a keyboard input and a monitor to show what the user has entered. Because of its size and configuration, it is the predecessor of the minicomputer, a computer affordable by small businesses.

Remington Rand, builder of the UNIVAC, completes the Livermore Advanced Research Computer, or LARC, for Lawrence Livermore Laboratories; with 60,000 transistors, it is the first large scientific computer to use transistors. *See also* 1956 COMP.

Frank Rosenblatt [b. New York City, 1928, d. 1969] completes the Perceptron, or MARK 1, computer at Cornell University. It is the first computer that can learn new skills by trial and error, using a type of neural network that simulates human thought processes. *See also* 1949 BIO; 1991 COMP.

IBM launches the project 360, developed by Gene Amdahl [b. Flandreau, South Dakota, November 16, 1922]; the "360" stands for a guarantee of compatibility between computer peripherals over 360 degrees. *See also* 1956 COMP; 1964 COMP.

American Airlines, which also introduces a semiautomatic reservation system called the Reservisor, begins construction of SABRE, the first computerized airline reservation system and one of the first computer systems to operate in real time. SABRE will be completed and begin operations in 1962, but not be fully operational until 1965. *See also* 1944 COMP.

Earth science

On January 23 the *Trieste*, the second bathyscaphe built by Auguste Piccard, is piloted by naval Lieutenant Don Walsh [b. 1931] and Piccard's son Jacques [b. Brussels, Belgium, July 28, 1922] to the bottom of the Challenger Deep in the Pacific, believed at 10,912 m (35,800 feet) to be the deepest trench in the oceans. *See also* 1948 TRAN.

On April 1 the United States launches *Tiros 1*, the first weather satellite. *See also* 1963 EAR.

As lava from an eruption of Kilauea on the Big Island of Hawaii threatens the village of Kapoho, bulldozers are used to build a dam 6 m (20 ft) high and 5 km (3 mi) long to hold it back. The attempt fails, and lava overflows the dam and the village. *See also* 1973 EAR.

Ecology & the environment

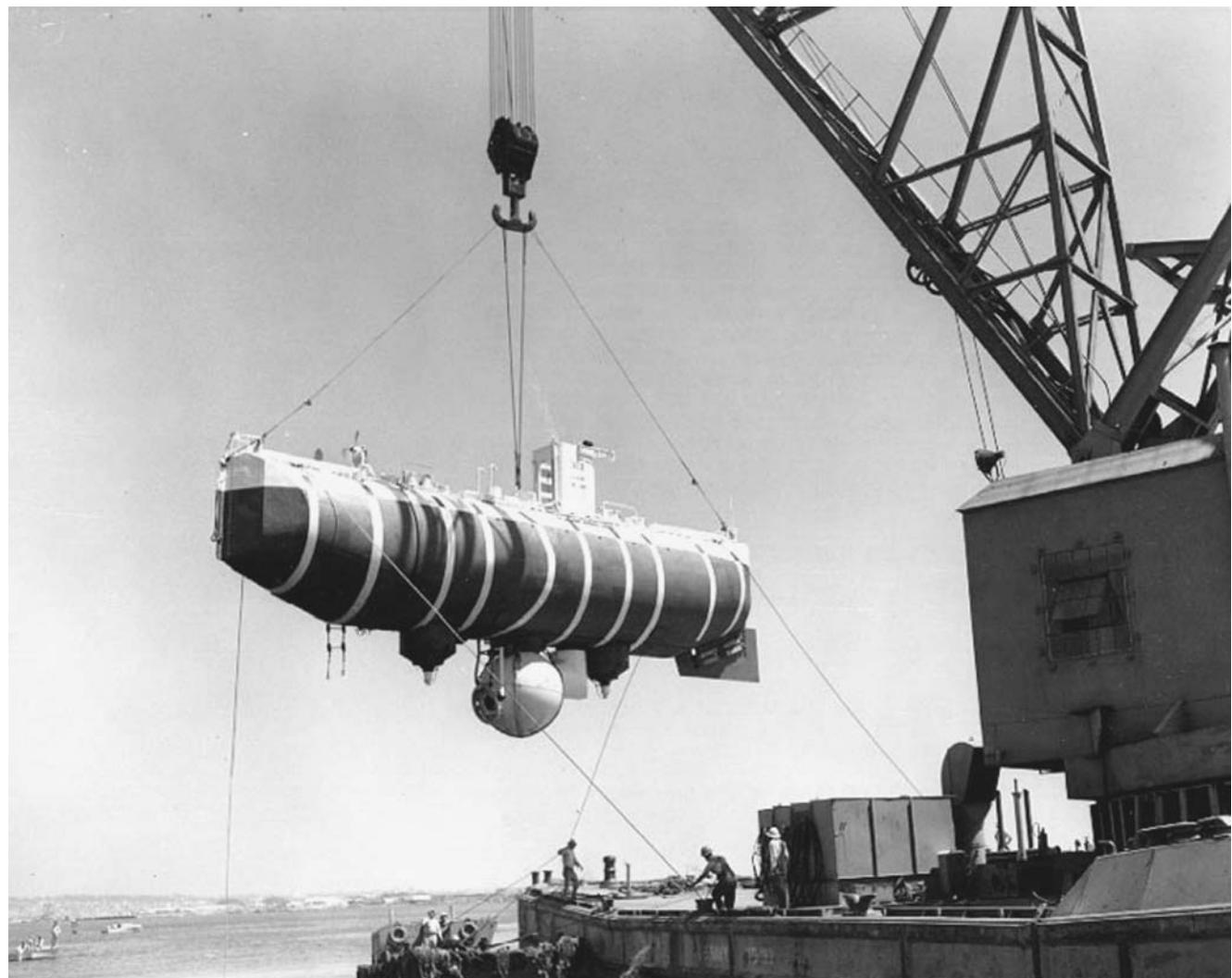
The first commercial reprocessing plant for radioactive wastes is built in West Valley, New York. *See also* 1956 ECOL; 1972 ECOL.

The U.S. Congress passes the Clean Water Act. *See also* 1963 ECOL.

Energy

The world's first boiling-water reactor is built in the United States. The reactor heats water under pressure to produce steam to power a generator. *See also* 1963 ENER.

The halogen lamp is introduced. The bulb is filled with a halogen gas that regenerates the filament, allowing it to glow at a much higher temperature. *See also* 1913 ENER.



BATHYSCAPHE TRIESTE BEING LOWERED INTO THE SEA Originally built by Auguste Piccard in 1953, the *Trieste* was purchased by and operated by the U.S. Navy in 1958. The bathyscaphe ("deep ship") was a navy vessel when it set the depth record in 1960 and later when it located a sunken nuclear submarine. The design was like an underwater dirigible — the large tank was filled with gasoline for buoyancy and the pilot and passenger rode in the small steel sphere suspended below the tank.

Geothermal power is produced for the first time in the United States at The Geysers, near San Francisco. *See also* 1903 ENER.

♥ Medicine & health

American electrical engineer Hal O. Anger [b. 1920] invents the "Gamma camera," a detector that allows the imaging of internal organs that are

labeled with a radioactive element. This will come to be a key part of the PET scan procedure. *See also* 1940 MED.

William H. Oldendorf [b. Schenectady, New York, March 27, 1925, d. Los Angeles, December 14, 1992] begins work about this time on what comes to be known as computerized axial tomography (CT or CAT scans). Working

at the University of California in Los Angeles, independently of researchers in South Africa and Great Britain, Oldendorf writes medical papers and obtains patents in the field, but fails to attract enough interest for development. In 1975 he (along with Godfrey Newbold Hounsfield [b. Newark, England, August 28, 1919], who did succeed in

obtaining development support) receives the Albert and Mary Lasker Award. *See also* 1957 MED.

Physician John Charnley [b. Bury, Lancashire, England, 1911, d. 1982] implants a two-part joint replacement made of plastic and cobalt-chrome into a human to replace a damaged joint. *See also* 1938 MED.

Wilson Greatbatch [b. Buffalo, New York, September 6, 1919] files a patent for an implantable pacemaker that permanently regulates heartbeat. *See also* 1958 MED.

About this time some women enlarge or reshape their breasts with a semiliquid plastic in a bag that is implanted in the skin; the plastic material is silicone, familiar to many by its trade name as the toy Silly Putty. About 2,000,000 women will use the implants in the next 30 years. *See also* 1992 MED.

Sir Macfarlane Burnet of Australia and English biologist Peter Brian Medawar win the Nobel Prize in physiology or medicine for their study of immune reactions to tissue transplants. *See also* 1949 MED; 1953 MED.

❖ Physics

Rudolf Ludwig Mössbauer [b. Munich, Germany, January 31, 1929] discovers that it is possible to make gamma rays with a very narrow wavelength and measure very accurately any change in wavelength. Almost immediately the Mössbauer effect is used to confirm Einstein's general relativity theory. Robert Vivian Pound [b. Ridgeway, Ontario, May 16, 1919] and Glen A. Rebka use the Mössbauer effect to measure the change in frequency of gamma rays (gravitational redshift) between the foot and top of a water tower, confirming the theory of general relativity. *See also* 1961 PHY.

Luis Alvarez announces his discovery in bubble chambers of very short-lived particles, which are termed "resonances." *See also* 1955 TOOL; 1968 PHY.

Norwegian-American physicist Ivar Giaever [b. Bergen, Norway, 1929] demonstrates electron tunneling through a thin oxide between two metals at superconducting temperatures. *See also* 1973 PHY.

I Tools

Theodore Harold Maiman [b. Los Angeles, July 11, 1927] develops the first laser in May using a ruby cylinder with polished end surfaces that act as mirrors; it is the first light source that can supply coherent light. *See also* 1958 TOOL; 1965 TOOL.

Donald Glaser of the United States wins the Nobel Prize for physics for developing the bubble chamber for subatomic study. *See also* 1952 TOOL.

↗ Transportation

Transit I-B, the first navigational satellite, is launched by the United States on June 22.

1961

★ Astronomy

On December 12 the Soviets launch *Venera 1*, the first space probe intended to reach another planet — Venus — but contact with it is lost.

❖ Biology

Marshall Nirenberg works out the first "letter" of the genetic code when he shows that the combination of nucleotides UUU (three uracil bases in a row) in RNA codes for the amino acid phenylalanine. *See also* 1966 BIO.

Robert William Holley [b. Urbana, Illinois, January 28, 1922, d. Los Gatos, California, February 11, 1993] produces purified samples of three different varieties of transfer-



Marshall Warren Nirenberg

[b. New York City, April 10, 1927]

In 1961 Nirenberg became the first person to determine what one letter of the genetic code stands for, using RNA. This opened the way for Nirenberg and colleagues to crack the genetic code completely by 1966, demonstrating which sequence of three nucleotide bases (a codon) determined each of 20 amino acids, along with similar three-letter codes for start and stop.

Element 103, named lawrencium (Lr) in honor of Ernest Lawrence, founder of the Lawrence Radiation Laboratory, where the new element is created, is produced by a team led by Albert Ghiorso.

Melvin Calvin of the United States wins the Nobel Prize in chemistry for his work on the chemistry of photosynthesis. *See also* 1957 BIO.

☛ Communication

In the United States, FM radio stations begin to broadcast in stereophonic sound. *See also* 1958 COMM; 1986 COMM.

IBM introduces the Selectric typewriter, in which characters are printed on paper by a rotating ball while the carriage remains fixed. *See also* 1935 COMM; 1964 COMM.

▀ Computers

John McCarthy introduces the concept of time-sharing (the MAC or Multiple Access Computer), which allows several users to use a computer at the same time. *See also* 1962 COMP.

IBM completes the 7030 computer for Los Alamos laboratories, where it will be used by scientists from the U.S. Atomic Energy Commission. Containing 169,100 transistors and nicknamed "Stretch," it is supposed to be 100 times faster than IBM's 704 mainframe computer, but it falls short and is only about 30 times as fast. *See also* 1960 COMP; 1964 COMP.

⊕ Earth science

Robert Sinclair Dietz [b. September 14, 1914, d. May 19, 1995] suggests that expansion of oceanic crust might move continents, a process he calls

Lasers

In 1916 and 1917 Albert Einstein continued his study of the physics of light. Among other things, Einstein showed that molecules that had been suitably energized would emit light of a single color, or monochromatic light. He calculated that when an excited molecule is hit by an electromagnetic particle (photon), the molecule will fall to a lower energy level and emit an identical photon moving in the same direction. The net result is two photons, where one existed before, amplifying the signal.

After World War II, uses were found for this effect. The effort started in 1951 when Charles Townes wanted to produce stronger microwaves. These could only be produced by a very small vibrator. As Townes was waiting on a park bench for a restaurant to open, it occurred to him that ammonia molecules were about the right size to vibrate at the needed speed. He did some quick calculations on the back of an envelope and concluded that he could pump energy into ammonia gas and the molecules would emit microwaves. He soon built the first device that produced microwave amplification by stimulated emission of radiation; he named this the maser after the initials of the process.

Various people, including Townes, thought that the same principle could be used to amplify light, although the technical problems were more difficult. Arthur Schawlow proposed using this method for amplification of light in 1958. Eventually, however, the patent office gave credit for developing light amplification by stimulated emission of radiation, or the laser, to Columbia University graduate student Gordon Gould, who conceived of a laser on November 11, 1957. The first effective laser was built by Theodore Maiman in May, 1960, although he knew nothing of Gould's work.

The laser produces absolutely monochromatic light, that is,

light of a single frequency. A second important property of the laser is that the light waves all travel in exactly the same direction and are in step. Light with these properties is called coherent light. One important property of a coherent light beam is that it does not spread when traveling through space. Therefore, a laser can carry a lot of energy into a small spot, heating the target spot by discharging the energy. Consequently, one of the first uses of lasers was in cutting and welding, both in heavy industry and medical practice. Surgeons use lasers as scalpels and ophthalmologists use them to weld damaged retinas in place. Others are working on devices to use laser power to ignite the fusion of hydrogen for a power source for the future.

Because laser light diverges very slowly, a laser beam can be used to determine how level a surface is. Farmers have used lasers to make certain that fields are level; this helps in protecting fields from erosion. Carpenters use lasers as levels, also.

Lasers are also part of the ongoing optical revolution, in which electronic devices are replaced by photonic devices. A photonic device uses photons instead of electrons. The long-distance fiber-optic networks that carry most telephone messages depend on photonic devices, for example. Lasers are an excellent source of photons for many of these devices. As tools for photonic switches improve, the development of photonic computers seems likely.

Lasers have also become ubiquitous in our daily life. Every compact disk or DVD player or writer incorporates a laser, and a laser beam scans the bar code on packaged goods. Lasers are also used to produce holograms — three-dimensional images such as those found on credit cards.

Military engineers have dreamed of lasers as weapons. Because the energy remains bundled in a narrow beam, a powerful laser could destroy an enemy warhead in space. Success in this specific endeavor is lacking, but use of lasers for guiding bullets or rockets is common.

sea-floor spreading. *See also* 1956 EAR; 1962 EAR.

The *Cuss I*, a converted oil-drilling rig, is used to drill a core from the ocean bottom at a depth of 3.5 km (2.2 mi); it succeeds in drilling through 183 m (600 ft) of sediment to reach the basalt floor of the ocean. *See also* 1947 EAR.

MIT meteorologist Edward N. Lorenz [b. West Hartford, Connecticut, 1917] accidentally finds the first mathematical system with chaotic behavior in a computer model of

how the atmosphere behaves — small changes in initial atmospheric conditions create large changes over time, making weather prediction inherently difficult. This becomes known as "the butterfly effect," since it appears that even the flutter of a butterfly's wings alters the atmosphere enough to affect weather several days later. His work attracts attention in other fields, leading to a new branch of mathematics, chaos theory. *See also* 1903 PHY.

Ecology & the environment

Investigations in Scandinavia and the U.S. Adirondack mountains confirm that acidity is increasing in small lakes, killing some species. The cause of the increase is believed to be acid precipitation resulting from air pollution, which becomes known as acid rain. *See also* 1959 ECOL; 1974 ECOL.

Electronics

Robert Noyce at Fairchild

develops the first planar integrated circuit, incorporating six transistors, that is suitable for mass production. *See also* 1964 ELEC.

Energy

Recognizing that peak electric loads differ in France and the United Kingdom, both by time of day and day of the week, engineers plan and build the Cross-Channel Cable for transferring extra electric power from one side of the channel to the other.

The chip

A transistor is essentially a replacement for a vacuum tube. When tiny transistors replaced bulky vacuum tubes, the first applications resulted in electronic devices that accomplished the same as tube-based devices, but were much smaller. This encouraged engineers to build more functions into the same devices since there was now more room. By the end of the 1950s, electronics manufacturers were faced with circuits of increasing complexity. Computers, for example, contained tens of thousands of transistors. Assembly often required hundreds of thousands of interconnections, all of which had to be soldered by hand.

Electronic devices, such as computers and radios, use several different types of components. Some are very fast switches. Others act as electronic gates, allowing certain messages to get through while rejecting others, or restricting flow of current to a single direction. In a computer such gates become logic circuits that, for example, combine two statements into one using the electronic equivalents to the logical connectives *and*, *or*, or *if-then*. Another component amplifies a signal. After the invention of the transistor, various configurations of transistors were created to perform these functions, components still referred to by such traditional names as resistor, capacitor, diode, and so forth. In each case the method was to add specific impurities to different regions of a semiconductor chip, a process called doping.

The idea of placing several components on a single chip came separately to two people who worked independently.

Jack Kilby, an electronics engineer, in 1958 joined a team at Texas Instruments that studied ways to reduce the size of com-

puter circuits. Kilby created a semiconductor chip that carried an oscillator made of several components, such as switches, resistors, capacitors, and diodes, all made from doped semiconductors. Although these components were on a single chip, Kilby had not developed a suitable way to connect them, and had to create interconnections in the traditional way. He demonstrated his oscillator-on-a-chip to executives from Texas Instruments on September 12, 1958, and filed for a patent a few months later.

Robert Noyce, a physicist, was the head of research at the recently founded Fairchild Semiconductor. That company had developed the "planar" technology for the manufacture of transistors. In that method, large numbers of transistors were created on a single wafer, which subsequently was cut up to yield the single transistors. Noyce realized that this technology would be suitable for creating an entire circuit on such a wafer. But he also found a way to make connections between the components on the wafer by laying down conducting tracks. The result is termed an integrated circuit, but most people simply call it a chip.

Noyce filed a patent for his integrated circuit one year after Kilby did, and was granted it in April 1961. Kilby's patent application was rejected because he had not solved the problem of interconnecting the components on the chip.

A legal battle between Kilby and Noyce ensued, which ultimately was won by Noyce by decision of the Court of Customs and Patents Appeals in November 1969. Fairchild Semiconductor and Texas Instruments, however, had already agreed to share the licensing of integrated circuits in 1966. Noyce and Kilby, regarded by the technical community as coinventors, a view both have accepted, jointly received the National Medal of Science for their invention.

The cable opens in December and is capable of transferring up to 160,000 kilowatts of power at 200,000 volts. *See also* 1963 ENER.

♥ Medicine & health

Judah Folkman [b. Cleveland, Ohio, February 24, 1933] suggests that a tumor might release a substance, which he calls tumor angiogenesis factor, that promotes the growth of blood vessels. Later studies will reveal that this hypothesis is correct. *See also* 1985 MED.

Frank L. Horsfall, Jr. [b. Mountain Grove, Missouri, January 9, 1905, d. February 19, 1971] announces that all

forms of cancer result from changes in the DNA of cells.

Julius Axelrod [b. New York City, May 30, 1912] announces that neurotransmitters such as epinephrine are recaptured by nerve endings at the synapse and reused. The neurotransmitter is kept in an inactive form but liberated in the active version when needed. *See also* 1970 BIO.

Thalidomide, widely used outside the United States to treat nausea during pregnancy, is shown to cause severe congenital abnormalities (in the United States the drug failed to win approval from the Food and Drug Administration). Chil-

dren with exposure at significant times in fetal development are born with deformed limbs and sometimes other abnormalities.

French-Australian physician Jacques Francis Albert Pierre Miller [b. Nice, France, April 2, 1931] determines that the thymus is part of the immune system by removing the thymus from newborn mice, who then fail to develop white blood cells (leukocytes) or lymph nodes and accept grafts they would normally reject. *See also* 1949 MED; 1965 BIO.

William F. House [b. 1923] develops the cochlear implant for people who are hearing

impaired. The cochlear implant is designed to produce useful hearing sensations by stimulating nerves inside the inner ear with electric currents that are controlled by a small microphone. *See also* 1960 BIO.

Jack Lippes introduces an inert plastic IUD (intrauterine device) for birth control. *See also* 1956 MED.

James Till and Ernest McCulloch at the Ontario Cancer Institute in Toronto, Canada, while studying how radiation destroys the blood cells of laboratory mice, find that they can rebuild the mice's supply of blood cells and prevent the mice from dying by giving

them injections of bone marrow cells from other, genetically identical mice. Less than two weeks after injecting the bone marrow cells, Till and McCulloch examine the bone marrow and spleen of the recipient mice and discover lumps of blood cell colonies. Expecting to find only one kind of blood cell in each lump, they observe that each lump contains all types of blood cells, although derived from a single bone marrow cell. "It proved for the first time that there was such a thing as a stem cell," said McCulloch later. *See also* 1998 BIO.

Neal E. Miller [b. Milwaukee, Wisconsin, August 3, 1909, d. Hamden, Connecticut, March 23, 2002] proposes that the autonomic nervous system can be conditioned to control heart rate and other "involuntary" functions, a method now known as biofeedback.

★ Physics

Murray Gell-Mann and, independently, Yu'val Ne'eman [b. Tel-Aviv, Israel, 1925] and David Speiser and Alfred Tarski introduce what Gell-Mann christens "the eightfold way" to classify heavy subatomic particles. This scheme, now known by its group-theoretic designation as SU(3), is the beginning of the quark theory and a part of the standard model. *See also* 1953 PHY; 1964 PHY.

Philip Warren Anderson [b. Indianapolis, Indiana, December 13, 1923] develops the "Anderson Model" of local magnetic moments. *See also* 1977 PHY.

Yoichiro Nambu [b. 1921] proposes spontaneous symmetry breaking for particles based on an analogy with the transition to superconductivi-

ty. Below a certain temperature or energy level one type of particle would break into two or more. The idea later becomes central to electroweak theory and much of particle physics.

Robert Hofstadter of the United States and Rudolf Mössbauer of Germany share the Nobel Prize in physics, Hofstadter for his measurement of nucleons and Mössbauer for his work on gamma rays. *See also* 1957 PHY; 1960 PHY.

→ Transportation

Soviet cosmonaut Yuri Alekseyevich Gagarin [b. near Gzhatsk (Russia), March 9, 1934, d. near Kirzhach (Russia), March 27, 1968] becomes the first human being to orbit Earth, on April 12, in his 1.8-hour mission in *Vostok 1*. Soviet cosmonaut Gherman S. Titov [b. Verhnee Zhilino, Russia, September 10, 1935, d. Moscow, September 20, 2000] completes the first multi-orbit spaceflight, of 17 orbits and 25.6 hours duration, the *Vostok 2* mission, on August 6.

Alan Shepard, Jr. [b. East Derry, New Hampshire, November 18, 1923, d. Monterey, California, July 21, 1998] accomplishes the first U.S. spaceflight, the Mercury 3 suborbital mission of the *Freedom 7* space capsule, a flight of 15 minutes on May 5. U.S. astronaut Virgil I. (Gus) Grissom [b. Mitchell, Indiana, April 3, 1926, d. Cape Canaveral, Florida, January 27, 1967] completes a 16-minute Mercury 4 suborbital space mission in the craft *Liberty Bell 7* on July 21. *See also* 1958 TRAN; 1962 TRAN.

The first Saturn rocket, part of a series developed by the

United States for the Apollo program, under the direction of Wernher von Braun, has a successful test launch.

Explorer 9, launched by the United States, is the first satellite launched by an all-solid-propellant rocket.

OSCAR (Orbiting Satellite Carrying Amateur Radio), constructed by U.S. radio hams, is the first privately built satellite to be launched.

On May 14 the United States tests the engine for a nuclear-powered, robot-guided ramjet, designed to operate in a similar fashion to the later, nonnuclear cruise missiles. *See also* 1948 TRAN; 1964 TRAN.

U.S. President John F. Kennedy cancels the air force nuclear bomber project because he thinks cheaper and less problematic long-range missiles can accomplish the same goals. *See also* 1956 TRAN; 1964 TRAN.

1962

★ Astronomy

Japanese astrophysicist Chushiro Hayashi [b. Kyoto, Japan, July 25, 1920] and coworkers create evolutionary models for stars with masses ranging from 0.01 to 100 times that of the Sun. *See also* 1955 AST.

British astronomer Cyril Hazard determines that the radio source 3C 273 consists of two components by observing its occultation by the Moon. The source 3C 273 will be identified as a quasar a year later and later studies show a long jet emerging from it, the other component. The occultation makes it possible to determine the exact location of the quasar. *See also* 1963 AST.

Riccardo Giacconi [b. Genoa, Italy, October 6, 1931], Herbert Gursky, and Frank R. Paolini follow a suggestion by Bruno Rossi to use a rocket flight above the stratosphere to observe X rays from the universe. The X-ray telescope on the June 18 flight from White Sands, New Mexico, was targeted at the Moon, but the principal discovery is the X-ray source in Scorpio now known as Sco X-1, the first known X-ray source outside the solar system. *See also* 1966 AST.

The Sugar Grove radio telescope fiasco occurs. The U.S. attempt to build a 183-m (600-ft) fully steerable dish radio telescope, begun in 1959, is discontinued after expenditures of \$96,000,000. However, the 90-m (300-ft) steerable dish at Green Bank, West Virginia, is completed and begins successful operations. *See also* 1988 AST.

Peter van de Kamp announces that an analysis of over 2000 photographs of Barnard's star shows that its motion wobbles in a periodic fashion, which he interprets as meaning that a planet orbits the star. Later data will suggest that the wobble may be caused by a defect in the telescope used. *See also* 1973 AST.

On November 2 the McMath Solar Telescope, the largest telescope designed for observing the Sun, is dedicated at Kitt Peak, Arizona. The Sun's image is captured by a mirror 2-m (80-in.) in diameter and reflected down a 237-m (780-ft) path into a study area where the image of the Sun can be observed at nearly 0.9-m (3-ft) wide or as a spectrum 21-m (70-ft.) long.

Seeing the whole sky

Astronomy is mainly an observational science, and advances in astronomy have often been the direct result of new observational techniques. When Galileo directed his telescope toward the night sky, he made more discoveries in a year than all the astronomers before him.

For the next 220 years, astronomers improved their ability to see the universe with better optical telescopes, but no one seems to have thought to go beyond light, even though both infrared and ultraviolet radiation were discovered at the start of the 19th century and the whole electromagnetic spectrum was known by early in the 20th century.

The discovery that we receive radio waves from the universe was quite accidental. In the 1930s, the radio engineer Karl Jansky recognized that one source of interference that disturbs short-wave communications on Earth is the center of our galaxy. When the first radio telescopes came into use during and after World War II, astronomers discovered that a large number of objects, including galaxies, the Sun, and even planets, emit radio waves. One of the early achievements of radio astronomers was the determination of the shape of our galaxy and the establishment of its spiral structure by observing the 21-cm (8-in.) line emitted by neutral hydrogen in the spiral arms. By the 1960s, astronomers using radio telescopes had begun to locate previously unsuspected celestial bodies — quasars and pulsars.

After World War II, astronomers also wanted to observe the universe in additional areas of the electromagnetic spectrum: infrared and ultraviolet light, X rays, and gamma rays. Earth's atmosphere, however, absorbs a large fraction of electromagnetic radiation in regions of interest to astronomers — nearly all other than visible light and radio frequencies. One solution was to use balloons and rockets to carry instruments high into the atmosphere to make observations possible. Infrared telescopes were placed on high mountains in dry regions where atmospheric absorption is less.

The technical breakthrough that completely solves the problem of atmospheric absorption was the development of artificial satellites in which instruments could be placed high above Earth's atmosphere. As early as 1962, only five years into the "Space Age," the United States launched the first telescope in space, *Orbiting Solar Observatory 1 (OSO 1)*. It did not bother with visible light, but measured solar electromagnetic radiation at ultraviolet, X-ray, and gamma-ray wavelengths — all unreachable from

Earth's surface (we do get some ultraviolet radiation, but most is stopped by ozone in the upper atmosphere). For two and a half months it observed the Sun, through some seven solar flares, and it also scanned the sky for gamma-ray sources.

The atmosphere is entirely opaque to X rays, which are usually emitted by highly energetic processes, such as matter falling into a black hole. The first X-ray cameras used by astronomers were pinhole cameras on balloons or rockets with special film emulsions that are blackened by exposure to X rays. Several dedicated X-ray satellites have been launched using special X-ray detectors to achieve better pinpointing of X-ray sources. *Uhuru* ("freedom" in Swahili), launched in 1970, discovered 339 new X-ray sources. The *Einstein Observatory (HEAO-2)*, put into orbit in 1978, was equipped with an X-ray telescope, a device that uses mirrors of a special geometry to focus X rays. In the 1990s a number of X-ray telescopes launched culminated in NASA's *Chandra X-ray Observatory* and the European Space Agency's *XXM-Newton*, which together have brought X-ray astronomy to levels comparable with visible-light astronomy.

On the other side of the electromagnetic spectrum the *Infrared Astronomical Satellite (IRAS)*, launched in 1983, was equipped with a 60-cm (24-in.) reflecting telescope. The telescope and the infrared detectors were cooled to 2°K by liquid helium. Although Earth's atmosphere absorbs much infrared radiation, the huge clouds of dust and gas inside our galaxy are transparent to infrared radiation; we can observe directly the nucleus of our galaxy in the infrared. During the ten-month period *IRAS* was operational, it discovered a huge number of infrared sources, including eight infrared galaxies. Late in the 1990s the European Space Agency flew its *ISO* infrared telescope, while NASA's *Space Infrared Telescope Facility (SIRTF)* was launched in 2003.

Gamma-ray photons — the most energetic photons of the electromagnetic spectrum — are emitted during most nuclear reactions. Large bursts of gamma rays coming from the universe were discovered in the 1960s — accidentally, again — by the American *Vela* system of satellites designed to monitor nuclear explosions on Earth. The sources of these gamma rays in space are thought to be supernovas or black holes. In the 1990s NASA's *Compton Gamma Ray Observatory* became the main engine of discovery.

The exploration of the entire sky at all electromagnetic wavelengths has revealed a universe more complex and more interesting than anyone could have expected from simply gazing at the Sun, Moon, and stars.

On March 7 the United States launches *OSO 1*, the *Orbiting Solar Observatory*, which is the first major astronomical satellite. See also 1947 AST; 1968 AST.

Ranger IV, the first U.S. space probe to reach the Moon, is launched on April 23; two other Ranger missions (*III* and *V*) fail this year.

On August 27 the U.S. space probe *Mariner 2* is launched; it is the first to reach the vicinity of another planet (Venus) and return scientific information.

On November 1 the Soviets launch *Mars I*, the first space probe aimed at Mars; contact is lost at about 106,000,000 km (66,000,000 mi) from Earth.



THE McMATH-PIERCE SOLAR TELESCOPE ON KITT PEAK Kitt Peak National Observatory, part of the U.S. National Optical Observatory, supports the world's most diverse collection of astronomical observatories for nighttime optical and infrared astronomy and daytime study of the Sun. The dramatically different McMath-Pierce Solar Telescope (originally named for Robert R. McMath and renamed in 1990 to honor Keith Pierce as well) stands out among the conventional domes for other optical telescopes (and also a steerable dish radio telescope).

Biology

Emile Zuckerkandl [b. Vienna, Austria, 1922] and Linus Pauling propose that changes in genetic material over time can be used as a "biological clock" to determine how long ago one species separated from another.

Sol Spiegelman [b. New York City, December 14, 1914, d. New York City, January 21, 1983] develops a technique for causing DNA and RNA to pair with each other. He is the

first to show that one strand of DNA carries the message, which is transmitted to RNA and from there into the manufacture of proteins. *See also* 1961 BIO; 1964 BIO.

English zoologist John Gurdon succeeds in creating clones of frogs using the fully differentiated intestinal cells of adult frogs, although the tadpoles produced all die before they develop into adults. *See also* 1952 BIO; 1984 BIO.

Rodney Robert Porter [b.

Newton-le-Willows, England, October 8, 1917, d. Winchester, England, September 7, 1985] uses the enzyme papain to split antibody molecules into sections and maps their peptide-chain structure. *See also* 1959 BIO; 1972 BIO.

Francis Crick and Maurice Wilkins of England and James Watson of the United States win the Nobel Prize in physiology or medicine for their determination of the molecular structure of DNA. *See also* 1953 BIO.

Chemistry

Neil Bartlett [b. Newcastle, England, September 15, 1932] demonstrates that compounds can be formed that include the noble gases by preparing xenon platinum hexafluoride; previously it was believed that the noble gases, such as xenon, could not combine with any other atoms to form molecules. *See also* 2000 CHEM.

Herbert Charles Brown [b. London, May 22, 1912] publishes *Hydroboration*, which describes his work with an

important new class of organic reagents based on borohydrides. *See also* 1979 CHEM.

John Kendrew and Max Perutz of England win the Nobel Prize in chemistry for their X-ray study of the structure of hemoproteins. *See also* 1960 CHEM.

Communication

Telstar, the first active communications satellite, is launched on July 10 and relays the first transatlantic television pictures. Each transmission lasts only 20 minutes because the ground stations in England and Maine can “see” the satellite simultaneously only for that time. *See also* 1960 COMM; 1963 COMM.

Emmet Leith and Juris Upatnieks [b. Riga, Latvia, May 7, 1936] develop off-axis holography that makes it possible to see images better and also to pack hundreds of images onto a single piece of photographic film. *See also* 1955 COMM; 1964 COMM.

Computers

The Atlas I, a computer built by Manchester University, incorporates virtual memory (an extension of working memory) and multitasking (the simultaneous running of two or more programs). *See also* 1948 COMP.

Earth science

Harry Hammond Hess [b. New York City, May 24, 1906, d. Woods Hole, Massachusetts, August 25, 1969] develops the theory of sea-floor spreading; new crust is created at mid-ocean ridges and moves toward deep-sea trenches, where it descends back into the mantle. Hess proposes that

convection currents in Earth’s mantle may be the cause of sea-floor spreading. *See also* 1961 EAR; 1967 EAR.

The explosion of a nuclear bomb at a great altitude in the atmosphere, called Project Starfish, causes long-lasting disturbances of the Van Allen radiation belts that surround Earth. *See also* 1958 EAR.

On October 31 the United States launches *Anna I-B*, the first satellite intended for accurately measuring the shape of Earth. *See also* 1958 EAR.

Ecology & the environment

Silent Spring by Rachel Carson alarms environmentalists and makes the general public aware of the danger of introducing chemicals into the environment. In the book Carson links pesticides such as DDT to an alarming decline in populations of eagles and other wildlife, which ingested the pesticides as they ate contaminated food. The pesticides thin eggshells, resulting in very low rates of reproduction. Carson points out that the pesticides accumulate in human tissues, too, and are passed from pregnant women to their fetuses. *See also* 1961 ECOL; 1963 ECOL.

Eugene J. Houdry patents the catalytic muffler, which reduces emissions of pollutants by automobiles.

Electronics

Nick Holonyak, Jr. [b. Ziegler, Illinois, November 3, 1928] develops the first practical light-emitting diode (LED), a semiconductor device that produces light when an electric current flows through it.

Energy

In Great Britain the world’s first advanced gas-cooled reactor, fueled by enriched uranium, is built. *See also* 1956 ENER.

Materials

William J. Buehler at the Naval Ordnance Laboratory discovers that cooled nitinol, an alloy of titanium and nickel, “remembers” the shape it possessed when hot if heated again; NASA will use this material for the construction of an antenna of an artificial satellite, which unfolds when heated with an electric current. *See also* 1932 MATR; 1987 MATR.

Mathematics

Tibor Rado discovers the first example of a function that is not computable. Proof of the existence of noncomputable functions, in the sense that a Turing machine cannot compute them, demonstrates that such functions exist, but the existence proof does not provide specific examples. *See also* 1936 MATH.

Medicine & health

Venezuelan-American geneticist Baruj Benacerraf [b. Caracas, October 29, 1920] and coworkers discover that the three-dimensional physical structure of antibodies determines their activity. *See also* 1980 MED.

Doctors split the brain of a patient with rapidly worsening seizures into two halves, a procedure that will not only relieve the symptoms but also allow Roger Wolcott Sperry [b. Hartford, Connecticut, August 20, 1913, d. Pasadena, California, April 17, 1994] and coworkers to continue with a

human subject a series of experiments they have been conducting on animals with split brains. Sperry will show with this and subsequent patients that the two parts of the brain can work independently and that left brain tends to be concerned with language and analysis, while the right brain specializes in spatial perception and emotions. *See also* 1981 BIO.

Lasers are used in eye surgery for the first time. *See also* 1960 TOOL; 1985 MED.

Physics

Lev Borisovich Okun [b. Sukhinichi (Russia), July 7, 1929] introduces the term *hadron* to represent collectively particles that are affected by the strong force; for example, protons, neutrons, pions, and kaons are hadrons, while the leptons, such as electrons, muons, and neutrinos, are not. *See also* 1954 PHY.

Brian David Josephson [b. Cardiff, Wales, January 4, 1940] discovers that if two superconductors are separated by a few angstroms, pairs of electrons (Cooper pairs) pass from one to the other superconductor. The current flow, or Josephson effect, has since been exploited in various devices, especially the Superconducting Quantum Interference Device, or SQUID, a very sensitive magnetometer. *See also* 1957 PHY.

Leon Lederman, Jack Steinberger [b. Bad Kissingen, Germany, May 25, 1921], and Melvin Schwartz [b. New York City, November 2, 1932] discover in an attempt to produce a beam of neutrinos that after passing through a 13.5 m (44.3 ft) steel wall made from the

cut-up deck plates of a dismantled cruiser as shielding, the beam creates muons. A group headed by Gordon Danby at Brookhaven National Laboratory performs the actual experiment. This result is explained as there being two forms of neutrinos — the muon neutrino, sometimes called the mu neutrino, and the electron neutrino. When the tauon is discovered in 1975, it will be assumed that there must also be a third kind of neutrino to match the third of the lepton trio (electron, muon, and tauon). *See also* 1988 PHY.

Lev Landau of the Soviet Union wins the Nobel Prize for physics for his work on superfluidity in liquid helium. *See also* 1958 PHY.

I Tools

Unimation in the United States markets the world's first industrial robot; it was originally developed by Georg C. Devol, for which he received a patent in 1961. General Motors installs these robots on its assembly lines. *See also* 1954 TOOL; 1964 TOOL.

D.N. Nasledov reports the first observation of laser activity by a semiconductor, the emission of infrared light from a gallium arsenide diode. Several teams of researchers in the United States, notably one led by Marshall I. Nathan at IBM, develop semiconductor p-n junction lasers, the first lasers built on the same general principles as the transistor. *See also* 1970 ELEC.

A 104-kiloton underground nuclear explosion in Nevada creates Sedan Crater in a Project Plowshare experiment in the use of fission power for earth moving. The crater is

390 m (1280 ft) in diameter and 98 m (320 ft) deep. *See also* 1957 ENER; 1967 ENER.

► Transportation

The *Savannah*, the first nuclear merchant ship, is launched with sea trials that begin on March 23. It will travel more than 725,000 km (450,000 mi) but, because of high running costs, it is decommissioned in the fall of 1971. *See also* 1954 TRAN; 1967 TRAN.

Soviet cosmonaut Andrian Nikolayev [b. Chuvash (Russia), September 5, 1929] is launched on August 11 for what becomes a 64-orbit *Vostok 3* mission, landing by parachute; this flight is a dual launch with the *Vostok 4* mission one day later, on August 12, carrying cosmonaut Pavel Popovich [b. Uzin (Ukraine), October 5, 1930] on a 48-orbit mission. The spacecraft pass within 6.5 km (4 mi) of each other.

On February 20 John Glenn, Jr. [b. Cambridge, Ohio, July 18, 1921] completes the first orbital flight by an American, the Mercury 6 mission of the craft *Friendship 7*, in three orbits. U.S. astronaut M. Scott Carpenter [b. Boulder, Colorado, July 7, 1921] completes the three-orbit Mercury 7 space mission in the craft *Aurora 7* on May 24. On October 3 U.S. astronaut Walter Schirra [b. Hackensack, New Jersey, March 12, 1923] completes a six-orbit Mercury 8 mission aboard the *Sigma 7* craft.

1963

► Anthropology

Ice age skeletons found in Romito Cave near Cosenza,

Italy, include that of a dwarf. Later analysis will suggest that the 17-year-old dwarf was accepted by the hunter-gatherers, despite the fact that he could not have contributed much to the community.

Lascaux Cave, home of the most famous cave paintings, dating back 17,000 years, is closed to the public to prevent damage to the art caused by the increased humidity from people's breath. An exact duplicate nearby will be constructed for tourists to visit. *See also* 1940 ANTH.

★ Astronomy

Dutch-American astronomer Maarten Schmidt [b. Groningen, Netherlands, December 28, 1929] reports his discovery of the extraordinary large redshift of the object 3C 273. The redshift corresponds to a recession velocity of 47,400 km (29,450 mi) per second, the first recognition of a quasar. *See also* 1960 AST; 1965 AST.

► Biology

John Burdon Sanderson Haldane [b. Oxford, England, November 5, 1892, d. Bhubaneswar, India, December 1, 1964] in his speech "Biological Possibilities for the Human Species of the Next Ten-Thousand Years" introduces the term *clone* in its meaning of an organism created by scientists from cells of an existing organism (biologists long have used the word to describe offspring of plants such as strawberries or spider plants produced when a tendril of the adult plant takes root, or offspring of other plant and protist methods of asexual reproduction).

Chinese scientist Tong Dizhou

[b. Zhejian Province, China, 1902, d. July 30, 1979] produces a genetic copy (clone) of a fish, a golden carp, by inserting the DNA from the cell of male carp into the egg of a female, replacing the DNA of the female. It is the first successful fish clone. *See also* 1981 BIO.

Sir John Eccles of Australia and Alan Hodgkin and Andrew Huxley of England win the Nobel Prize for physiology or medicine for their study of the mechanism of transmission of neural impulses. *See also* 1953 BIO; 1952 BIO.

□ Chemistry

William N. Lipscomb [b. Cleveland, Ohio, December 9, 1919] writes *Boron Hydrides*, which concerns compounds of boron and hydrogen, a.k.a. boranes. Boranes cannot be explained in terms of bonding based on pairs of electrons, but Lipscomb shows how three atoms can share one electron pair, which describes boranes and other similar molecules. *See also* 1976 CHEM.

Roald Hoffmann [b. Złoców, Poland, July 18, 1937] describes what comes to be known as the extended Hückel method for determining the molecular orbitals of hydrocarbons and boron hydrides, which will in the next three years lead to development with R. B. Woodward of the Woodward-Hoffmann rules for explaining whether certain cyclic hydrocarbons can be formed. *See also* 1981 CHEM.

Giulio Natta of Italy and Karl Ziegler of Germany win the Nobel Prize in chemistry for their synthesis of polymers for plastics. *See also* 1953 CHEM.

Quasars

Many scientific discoveries have put an idea scientists had — a theory — on a stronger footing. Examples are the discovery of the cosmic background radiation that provided a confirmation of the big bang theory, and the discovery of pulsars, which made reality of the idea of neutron stars. The discovery of quasars, however, only caused bewilderment among astronomers. The consequence of this discovery was that one either had to question the validity of the yardstick of the astronomer, the redshift, or to agree that there are processes out there for which there was no explanation yet.

The quasar problem began this way: During the 1950s, radio astronomers discovered a number of very compact radio sources. Because radio telescopes at that time could not pinpoint celestial objects very accurately, it was difficult to find these objects with a telescope. One of these compact sources, known as 3C 273, was occulted by the Moon in 1962, however, and its exact position could be established. Photos taken with the Hale 5-m (200-in.) telescope at Mt. Palomar showed a starlike object at that position. However, its spectrum was unusual: It contained absorption lines that could not be identified. It, and later others like it, was called a quasistellar radio source (that is, identified by radio, it looks like a star, but is not a star), or quasar for short.

In 1963 Maarten Schmidt discovered that the absorption lines in the spectrum of quasar 3C 273 were common ones, but shifted toward the red end of the spectrum by an extraordinary amount.

During the following years astronomers discovered a large number of quasars with large redshifts.

It was commonly held among astronomers that the radial redshifts (that is, directly away from Earth) observed in the spectra of extragalactic systems are Doppler shifts caused by velocity; these systems have because they participate in the expansion of the universe. Redshifts caused by the expansion of the universe are called cosmological redshifts. If the redshifts of quasars are cosmological, quasars are the farthest objects ever observed in the telescope. Furthermore, if quasars can be observed over such distances, their energy output must be enormous.

Not all astronomers, however, believed at first that quasars have cosmological redshifts. American astronomer Halton Arp notably disputed this idea. But the more that was learned about quasars, the more it appeared that the redshifts are cosmological. For one thing, astronomers found that some quasar images are distorted by gravitational lenses, regions of high gravity between the quasars and Earth that act as lenses. Quasars must be great distances beyond the lenses, which are generally very far away themselves.

Accepting, then, that quasars produce great amounts of energy, what are they? The most popular belief is that quasars are massive black holes in the centers of distant galaxies, galaxies so far away that their stars and dust cannot be seen. Sometimes it is possible to observe a faint light from the galaxy, which helps verify this idea. Our own galaxy has such a black hole at its center. Perhaps if you were near 3C 273 and looked toward the Milky Way galaxy, you would see only the quasar at its center.

Communication

The communications satellite *Syncom 2*, launched on June 26, becomes the first artificial satellite to go into a geosynchronous orbit; that is, an orbit that is matched to Earth's rotation so that the satellite stays directly above one location on Earth's surface. It demonstrates the feasibility of commercial satellite communications. *See also* 1945 COMM.

A direct telephone link, called the hot line, is established between the White House in the United States and the Kremlin in the Soviet Union. *See also* 1960 COMM; 1964 COMM.

The compact cassette tape cartridge for recording and playing back sound is introduced by Philips of the Netherlands.

"Instant" color film, or self-developing color photography, is introduced by the Polaroid Land Company. *See also* 1948 COMM.

Computers

Ivan E. Sutherland [b. Hastings, Nebraska, May 16, 1938] writes a doctoral thesis, "Sketchpad, A Man-Machine Graphical Communication System," announcing that computers will play an important role in the manipulation of images. Sketchpad is a software program that allows the creation of graphics on a

video terminal using a lightpen. *See also* 1972 COMM.

Earth science

Carl Sagan detects the formation of adenosine triphosphate (ATP) in a mixture of chemicals, reflecting what are thought to be the early conditions on Earth. ATP is an important biochemical used in storing energy. *See also* 1953 BIO.

Frederick John Vine [b. Chiswick, London, June 17, 1939] and Drummond Hoyle Matthews [b. February 5, 1931, d. July 20, 1997] show that the residual magnetism of the floor of the Indian Ocean changes polarity in a periodic fashion, convincing evidence

that sea-floor spreading has occurred. Since Earth's magnetic field reverses from time to time, the magnetic "stripes" also indicate the rate of spreading. *See also* 1961 EAR; 1966 EAR.

J. Tuzo Wilson [b. Ottawa, Canada, October 24, 1908, d. Toronto, Canada, 1993] proposes that the Hawaiian Islands are formed as the spreading sea floor moves over a region of upwelling rock, or "hot spot," in the mantle. *See also* 1972 EAR.

Verner E. Suomi [b. Eveleth, Minnesota, December 6, 1915, d. Madison, Wisconsin, July 30, 1995] invents the modern spin-scan weather satellite, the main form of weather satellite

used from 1966 through the end of the 20th century. It spins a hundred times a second for stability, scanning a strip of Earth in each rotation of a geosynchronous satellite. Tilting the satellite more with each spin over a 30-minute period provides an image of the entire visible face of the planet. *See also* 1960 EAR; 1966 EAR.

❖ Ecology & the environment

Congress passes the nation's first Clean Air Act. *See also* 1960 ECOL; 1964 ECOL.

The Limited Test Ban Treaty, signed by the United States, United Kingdom, and Soviet Union, prohibits testing of nuclear weapons above ground, under water, and in space. *See also* 1954 ECOL.

■ Electronics

NASA launches the IMP satellite, the first to contain integrated circuits. *See also* 1958 ELEC; 1964 ELEC.

Semiconductor diodes that use electron tunneling go on sale only six years after the tunneling effect is discovered by Leo Esaki. *See also* 1957 PHY.

❖ Energy

In Canada the first CANDU (Canadian Deuterium Uranium) reactors begin operating,

using uranium in a pressure tube surrounded by heavy water (deuterium oxide). *See also* 1947 ENER; 1971 ENER.

The world's largest pumped storage station is built at Blaenau Ffestiniog in Snowdonia national park in Wales. By pumping water to the top of a mountain when there is electricity to spare, the water's ability to use gravitational force to do work can be stored until needed to power generators that rectify changes in power output on the electric grid or supply power during peak need periods. *See also* 1991 ENER.

■ Food & agriculture

Ermal Fraze of the Dayton Reliable Tool and Manufacturing Company, Dayton, Ohio, obtains the patent on a method of attaching a ring to a scored portion of the top of a beverage can so that the resulting tab can be pulled away. Although not the first easy-opening can, this is the first such beverage can and will be quickly adopted by major canners of beer and soda.

Σ Mathematics

Paul Joseph Cohen [b. Long Branch, New Jersey, April 2, 1934] shows that Cantor's continuum hypothesis is independent of the axioms of set

theory, which means that there are at least two types of mathematics possible — one that says that the continuum hypothesis is true and one that says it is false. *See also* 1940 MATH.

Lotfi Zadeh [b. Baku, Russia, February 4, 1921] starts his work on fuzzy logic at the University of California at Berkeley. The first application will be 25 years later, when in Japan the Sendai underground train system (subway) is equipped with computers based on fuzzy logic.

♥ Medicine & health

A man has the kidney of a chimpanzee transplanted into him in an operation at Tulane Medical School in New Orleans, Louisiana. He survives for nine months. *See also* 1905 MED; 1992 MED.

Thomas Starzl [b. Le Mans, Iowa, March 11, 1926] and Francis Daniels Moore [b. Evanston, Illinois, August 17, 1913, d. Westwood, Massachusetts, November 24, 2001] perform the first liver transplant. *See also* 1953 MED; 1967 MED.

James Daniel Hardy [b. Newala, Alabama, 1918, d. Jackson, Mississippi, February 19, 2003] performs the first lung transplant. *See also* 1953 MED; 1967 MED.

❖ Physics

Nicola Cabibbo develops a theory of weak interactions that indirectly leads to the electroweak theory that is accepted today. *See also* 1957 PHY; 1967 PHY.

Murray Gell-Mann, while theorizing about entities that he thinks of as "kworks," reads the line "Three quarks for Muster Mark" in *Finnegans Wake*, which leads him to propose formally in 1964, when the theory is presented, that the basic particles he is discovering be called quarks, as they are to this day. *See also* 1964 PHY.

Eugene Paul Wigner and Maria Goeppert-Mayer of the United States and J. Hans D. Jensen of Germany share the Nobel Prize in physics, Wigner for the mechanics of proton-neutron interaction and Mayer and Jensen for their theory of nucleic structure. *See also* 1926 PHY; 1948 PHY.

I Tools

Friction welding is invented. *See also* 1898 MATR.

→ Transportation

U.S. astronaut L. Gordon Cooper [b. Shawnee, Oklahoma, March 6, 1927] is launched on May 15 for a 22-orbit Mercury 9 mission in the *Faith 7* space capsule.

Soviet cosmonaut Valery Bikovsky [b. Moscow, August 2, 1934] is launched on June 14 for an 81-orbit space mission in the craft *Vostok 5*. The first woman in space, Valentina Tereshkova-Nikolayeva [b. Maslennikovo, Russia, March 6, 1937] of the Soviet Union, is launched on a 78-hour, 48-orbit Soviet space mission, *Vostok 6*, on June 16, a dual launch with *Vostok 5*.



Carl Sagan

[b. New York City, November 9, 1934, d. Seattle, Washington, December 20, 1996]

Sagan promoted planetary astronomy and the search for intelligent life, becoming one of America's best-known scientists through television and popular books. He explained the runaway greenhouse effect on Venus and contributed to the theory that dust from large explosions, such as asteroid impacts, causes mass extinctions by lowering temperatures and stopping photosynthesis over all of Earth.

Polyot 1, the first satellite able to change its orbit, is launched by the Soviet Union.

A Rolls-Royce automobile with a diesel engine is produced, the first passenger car to use a small, light diesel in which the pistons are opposed, a type first suggested in 1885 but not perfected until this version. *See also* 1950 TRAN.

Robert Kearns invents the intermittent windshield wiper for automobiles. His patents will be infringed upon by major automobile manufacturers until 1990, after which they pay him royalties.

1964

★ Astronomy

German-American physicist Arno Allan Penzias [b. Munich, April 26, 1933] and Robert Woodrow Wilson [b. Houston, Texas, January 10, 1936], while trying to eliminate all static from a radio antenna, accidentally find a pervasive radio-wave background that they cannot explain. The microwave radiation at one frequency comes equally from all directions. *See also* 1948 AST; 1965 AST.

Robert Henry Dicke [b. St. Louis, Missouri, May 6, 1916, d. March 4, 1997] revives a suggestion made previously by George Gamow that the big bang would have left behind recognizable background microwave radiation. *See also* 1948 AST; 1965 AST.

Herbert Friedman and his group at the U.S. Naval Research Laboratory, using detectors mounted on rockets, discover X rays from the Crab Nebula. *See also* 1963 AST; 1968 AST.

The International Year of the Quiet Sun, a follow-up to the International Geophysical Year of 1958 - 59, begins on January 1 and will continue to December 31, 1965. The goal is for internationally coordinated studies of the Sun during the part of its 11-year sunspot cycle that has the least activity.

U.S. space probe *Ranger 7* takes the first good close-range photographs of the Moon. In all, 4316 pictures are taken by the six television cameras on board and relayed to Earth.

On November 28 the United States launches *Mariner 4*, which flies by Mars and takes 21 pictures of its surface, successfully transmitting them back to Earth. Its closest approach is 9850 km (6118 mi).

◆ Biology

Thomas F. Roth and Keith R. Porter discover the first receptors embedded in the cell membrane of an egg cell. They identify the coated pits that collect the precursor to yolk from the environment and the coated vesicles that carry the yolk into the interior of the egg cell. *See also* 1900 MED; 1973 MED.

Charles Yanofsky [b. New York City, April 17, 1925] and Sydney Brenner [b. South Africa, January 13, 1927] prove that the order of nucleotides in DNA is precisely collinear with the order of amino acids in proteins, an important step in the elucidation of protein synthesis. *See also* 1962 BIO.

Indian-American chemist Har Gobind Khorana [b. Raipur, India, January 9, 1922] synthesizes combinations of bases from nucleic acids and uses

them to demonstrate that genetic instructions are transmitted in combinations of three "letters" (that is, the bases). *See also* 1968 BIO.

Mark Richmond and Eric Johnston show that the same plasmid that carries resistance to penicillin in staphylococci also permits the bacteria that possess the plasmid to survive a mercury-based disinfectant. Other workers show that the plasmid confers resistance to a wide varied of normally toxic metals. *See also* 1959 BIO; 1967 BIO.

German-American biochemist Konrad Emil Bloch and Feodor Lynen win the Nobel Prize for physiology or medicine for their work on cholesterol and fatty acid metabolism. *See also* 1942 BIO; 1951 BIO.

▷ Chemistry

Scientists at the Joint Institute for Nuclear Research in Dubna, Russia, create element 104, rutherfordium (Rf), by bombarding plutonium with neon ions. It is the first transuranium element that is not a member of the actinide series of closely related metals.

Dorothy Hodgkin of England wins the Nobel Prize in chemistry for her analysis of the structure of vitamin B₁₂. *See also* 1956 CHEM.

◆ Communication

In his paper "On Distributed Communications," Paul Baran summarizes his concept for transmitting data through a distributed network; it is called packet switching, which he began to develop in 1960. Packet switching, which allows different parts of a message to take their own paths to a destination, where they are

rejoined, will become a key element of the Internet. *See also* 1960 COMM; 1966 COMM.

First plans for the Advanced Research Project Agency (ARPA) of the U.S. Defense Department to establish ARPANET, a computer network that can connect different types of computers and that uses packet switching for communication. The network will become operational in 1969. *See also* 1960 COMM; 1973 COMM.

Robert Lucky [b. Pittsburgh, Pennsylvania, January 9, 1936] of Bell Telephone invents the equalizer, a device that eliminates echoes in telephone lines and allows the development of very fast modems. *See also* 1958 COMM; 1969 COMM.

U.S. courts declare that software can be protected by copyright.

IBM Corporation develops the first automatic typewriter to use magnetic tape instead of a punched paper roll or punched tape to record keystrokes, the Magnetic Tape Selectric. *See also* 1961 COMM; 1969 COMM.

The International Telecommunications Satellite Organization (Intelsat) of the United States and 11 other countries is set up to develop a global commercial telecommunications satellite system. *See also* 1962 COMM; 1965 COMM.

Emmet Leith and Juris Upatnieks of the University of Michigan demonstrate the first practical hologram using lasers at the spring meeting of the Optical Society of America. It is a three-dimensional view of a model train, a stuffed bird, and a motorcycle toy. *See also* 1960 COMM; 1968 COMM.

Ole-Johan Dahl and Kristen Nygaard develop SIMULA, a language with the dual purpose of system description and simulation programming; a later version (SIMULA 67) includes the concept of "object." *See also* 1972 COMM.

John Kemeny [b. Budapest, Hungary, May 31, 1926, d. Hanover, New Hampshire, December 26, 1992] and Thomas Kurtz [b. Oak Park, Illinois, February 22, 1928] demonstrate BASIC (Beginners All-purpose Symbolic Instruction Code), a computer language for beginners. It will become the main programming language used by owners of personal computers, although most commercial programs for personal computers are written in more sophisticated languages. *See also* 1971 COMM.

IBM introduces PL I (Programming Language I), which, however, is unable to compete successfully with FORTRAN and COBOL. *See also* 1954 COMM; 1965 COMM.

The American Standard Association adopts ASCII (American Standard Code for Information Interchange), which, using seven bits, allows the transmission of 128 different characters; the ASCII standard is accepted in 1966 by the International Standard Organization.

IBM develops the first CAD system (computer-aided design), the system 2250. *See also* 1987 TOOL.

Computers

The IBM 360 computer, designed by Gene Amdahl, is introduced. The computer is compatible with a wide range of peripheral devices, which contributes to its becoming a

commercial success. *See also* 1960 COMP.

Control Data Corporation introduces the CDC 6600, designed by Seymour Cray [b. Chippewa Falls, Wisconsin, September 28, 1925, d. Colorado Springs, Colorado, October 5, 1996]. The CDC 6600 is the first supercomputer to become a commercial success. It has a speed of 9 megaflops (that is, 9,000,000 multiplications per second). IBM announces the IBM 90 supercomputer in response to the CDC 6600. *See also* 1961 COMP; 1968 COMP.

Construction

The 1289-m (4620-ft) Verrazano Bridge, the longest suspension bridge in the world at that time, opens to traffic in

New York City; it is designed by Othmar Ammann. *See also* 1931 CONS; 1981 TRAN.

Earth science

The submersibles *Alvin* and *Aluminaut* complete preliminary tests before going into full service. Submersibles are small underwater vehicles, equipped with viewing windows and arms for retrieving material, designed for research. They carry a small crew (three or four persons, typically) to ocean depths. *See also* 1967 EAR.

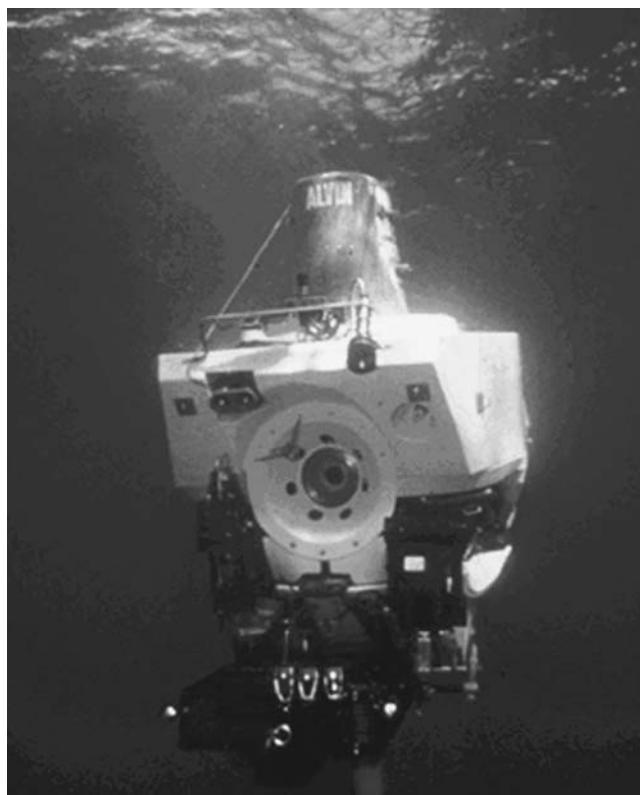
Bids to drill the Project Mohole are opened on July 12. The Mohole is intended to extend to the Mohorovicic discontinuity between the crust and the mantle of Earth. Later the project will be abandoned

as impractical. *See also* 1947 EAR.

The United States launches *Nimbus I* on August 28. It is the first weather satellite to be stabilized so that its cameras always point toward Earth. *See also* 1966 EAR.

Ecology & the environment

"The Genetical Evolution of Social Behavior" by British biologist William D. Hamilton [b. August 1, 1936, d. March 7, 2000] shows that the "altruistic" behavior of social bees and ants can be explained by the theory of evolution by natural selection: Female workers pass along more of their genes by encouraging reproduction by the queen rather than reproducing themselves.



THE SUBMERSIBLE ALVIN LAUNCHED ON A DIVE *Alvin*, owned by the U.S. Navy but operated by Woods Hole Oceanographic Institute, has been the most successful undersea research vehicle for science and also has recovered sunken thermonuclear bombs and explored the wreck of the *Titanic*. It carries four video cameras, bright lights, and two robot arms for retrieving samples. The three view ports for direct viewing are each 30 cm (12 in.) in diameter.

Hamilton uses mathematical arguments to propose that an action that endangers the individual but promotes the survival of more than two siblings, or more than eight first cousins, becomes advantageous by promoting the spread of the gene that triggers the behavior. This concept is later extended to become a fundamental tenet of sociobiology. *See also* 1975 BIO.

The Aswan Dam on the Nile is completed, resulting in profound ecological changes including increased schistosomiasis, decreased numbers of sardines in the eastern Mediterranean, and increased erosion of the Nile Delta.

The U.S. Congress passes the Wilderness Act, setting up a National Wilderness Preservation System. *See also* 1963 ECOL; 1965 ECOL.

■ Electronics

Zenith develops a hearing aid equipped with an integrated circuit, the same chip used as an amplifier in NASA's IMP satellite. The hearing aid is the first commercial product incorporating such a device. *See also* 1952 ELEC; 1963 ELEC.

■ Food & agriculture

The International Rice Research Institute starts the "green revolution" with new strains of rice that have dou-

bled the yield of previous strains if they are given sufficient fertilizer.

◊ Materials

Stephanie Kwolek [b. New Kensington, Pennsylvania, July 31, 1923] invents the high-strength, low-weight plastic Kevlar while working for Du Pont. One of the first practical applications, when the product is introduced in the 1970s, will be a bulletproof fabric. It also will be used in making tires, boat shells, and components for the aerospace industry. *See also* 1930 MATR.

Permanent press clothing is introduced, based on polyester fibers such as Dacron.

♥ Medicine & health

Baruch S. Blumberg [b. New York City, July 28, 1925] discovers the Australian antigen, which becomes the key to the development of a vaccine for hepatitis B. *See also* 1980 MED.

The U.S. Surgeon General's report on tobacco implicates smoking in lung cancer. *See also* 1953 MED.

Home kidney dialysis is introduced in the United Kingdom and the United States. *See also* 1956 MED.

❖ Physics

Murray Gell-Mann's paper "A Schematic Model of Baryons and Mesons" in February

Ecology and sociobiology

Ecology is the science of the relationship between organisms and their environment. Some aspects were studied as early as 1789 or perhaps even earlier. The word itself was coined in 1866 (it means "study of the house"). But ecology really came into its own after World War II.

One reason for this is certainly the environmental movement that began seriously in 1962 with Rachel Carson's book *Silent Spring* and intensified in the 1970s. The popularity of environmental causes attracted people to ecology, sometimes in the mistaken belief that ecology is the science of avoiding pollution. Biologists might date their own environmental movement from publication in 1967 of *The Theory of Island Biogeography* by Robert MacArthur and Edward O. Wilson, which explored stability and fragility of species in restricted habitats.

Another reason for gains in ecology in the 1960s and 1970s has been the postwar development of the computer. Ecology is very much concerned with numbers and mathematical models, since it treats a great many individuals interacting with each other and with their physical surroundings all at once. Prewar models of how populations behave were computed by hand or with mechanical calculators. By the mid-1970s, an ecologist could feed a formula into a computer and see how a population stabilized, became periodic, or exploded depending on the choice of a single parameter. With such a tool in hand, much of the work in

ecology during the 1960s and 1970s concentrated on finding how competition among species or individuals for niches — ways of living — affect populations. Energy distribution in populations also became easier to determine.

The realization in 1964 that apparently altruistic traits in species could be explained by the mathematics of Mendelian heredity led to sociobiology as a controversial offshoot of ecology. Calculations showed that among the social bees and ants a worker passes along more of her genetic heritage when the queen has all the children than when each worker has some of them (bee and ant workers are always female). Generalizing from this special example, Edward O. Wilson, a specialist in ants as well as biogeography, and others argued that many different types of social behavior in animals can be explained as mechanisms designed to transmit genes. Wilson's 1975 book *Sociobiology: The New Synthesis* aroused great controversy. People who believe that altruism in humans originates from nonbiological considerations fought against the precepts of sociobiology.

For a time, sociobiology was widely discussed, but popular interest in it faded. However, sociobiological ideas continue to influence much of the research on animal behavior (and some on human behavior). One scientific journal, for example, deals with *Behavioral Ecology and Sociobiology*. And while controversy over sociobiology is no longer in the popular press, thoughtful articles supporting or attacking the concepts continue to be a part of scientific discourse.

introduces the concept of quarks, particles of fractional charge that make up all baryons and mesons. He proposes three quarks called up, down, and strange. *See also* 1963 PHY; 1969 PHY.

Sheldon Glashow [b. New York City, December 5, 1932] and James D. Bjorken in August introduce a fourth quark species carrying “charm.” No one pays much attention to it until early in 1970 when Glashow, studying the problems with the Cabibbo theory, shows that charm will solve these problems. *See also* 1963 PHY; 1967 PHY.

Nicholas Samios leads a team at Brookhaven National Laboratory that discovers the omega-minus particle in the output of a particle accelerator. This clinches the case for Murray Gell-Mann’s eightfold way of classifying subatomic particles. *See also* 1953 PHY.

James W. Cronin [b. Chicago, Illinois, September 29, 1931], Val L. Fitch [b. Merriman, Nebraska, March 10, 1923], and coworkers discover that the neutral K meson breaks the rule that combines conservation of charge conjugation and parity (CP conservation). Because of the CPT theorem connecting CP conservation to time, this discovery also implies that time reversal is not invariant. *See also* 1957 PHY; 1967 PHY.

Peter Higgs [b. April 11, 1930] in Scotland (and other physicists independently) conceives of a field and a particle that give mass to all the other elementary subatomic particles. The particle becomes known as the Higgs particle or Higgs boson. Higgs suggests a mechanism of spontaneous symmetry break-

ing that gives other particles mass. *See also* 1954 PHY.

John Stewart Bell [b. Belfast, Northern Ireland, July 28, 1928, d. Geneva, Switzerland, October 1, 1990] proves what comes to be known as Bell’s theorem. This establishes a fundamental (but logic-defying) attribute of the behavior of particles under the rules of quantum mechanics that ultimately will be used to show that “spooky action at a distance,” as Einstein famously called it, actually exists. *See also* 1997 PHY.

Raymond Y. Chiao, Boris P. Stoicheff, and Charles Townes discover stimulated Brillouin scattering, in which a low intensity beam of light passes through a transparent substance but a light of high enough intensity is reflected from the same substance. *See also* 1972 PHY.

Stephan von Molnár [b. Leipzig, Germany, June 26, 1935] investigates the magnetic properties of europium.

I Tools

The first industrial robot in Europe is installed in a Swedish foundry for lifting castings from molds and placing them on a cooling bed. *See also* 1962 TOOL.

China explodes its first nuclear fission bomb above ground.

Charles Townes of the United States, Nikolay Gennadiyevich Basov, and Aleksandr Prokhorov win the Nobel Prize for physics for development of maser and laser principles in quantum mechanics. *See also* 1953 TOOL; 1957 TOOL.

→ Transportation

Soviet cosmonauts Vladimir Komarov [b. Moscow, March

16, 1927, d. Orenburg, Russia, April 24, 1967], Konstantin Feoktistov [b. Voronezh, Russia, February 7, 1926], and Boris Yegorov [b. Moscow, November 26, 1937], the first multiperson crew in space, complete a 16-orbit *Voskhod 1* mission on October 12.

The U.S. military cancels its plans for a nuclear-powered low-flying missile because its radioactivity would make it too dangerous. Some \$260,000,000 had been spent on the project. *See also* 1961 TRAN.

A high-speed rail link is opened between Tokyo and Osaka in Japan. Nicknamed “bullet” trains, these run with an average speed of 160 km/hr (100 mph). *See also* 1846 TRAN; 1973 TRAN.

1965

◀ Anthropology

Elwyn LaVerne Simons [b. Lawrence, Kansas, July 14, 1930] announces the discovery of the 30,000,000-year-old skull of an ape, which he names *Aegyptopithecus*. *Aegyptopithecus* is at this time the earliest known primate that is definitely a part of the hominid line, the line that eventually leads to *Homo sapiens*.

▲ Archaeology

In *Stonehenge Decoded* Gerald Stanley Hawkins [b. Norfolk, England, April 20, 1928, d. May 26, 2003] argues that the Neolithic megalith once served as a cross between an observatory and a computer, enabling the builders to compute the times of various astronomical events. *See also* 1450 BCE CONS.

★ Astronomy

Robert Dicke identifies the cosmic background radiation as that produced by the big bang, confirming that theory. *See also* 1964 AST.

Frederick Reines and Jacques Pierre Friederich (Friedel) Sellschop [b. Luderitz (Namibia), June 8, 1930, d. Johannesburg, South Africa, August 4, 2002] detect neutrinos from cosmic rays deep in a South African gold mine, the start of neutrino astronomy. Construction starts on the first neutrino telescope, which is built 1480 m (4850 ft) below ground in The Homestake gold mine in South Dakota. It is designed to record neutrinos produced by fusion reactions in the Sun’s core. The neutrinos are detected with a large vat of 615 tons of dry cleaning fluid (tetrachloroethylene). Chlorine in the cleaning fluid is changed to argon-37, which is both radioactive and a noble gas (fails to combine with other elements), when a neutrino strikes a molecule of tetrachloroethylene. The telescope detects about 15 atoms of argon-37 a month after it goes into operation, starting in 1967. *See also* 1956 PHY; 1978 AST.

Allan Sandage finds quasars that do not emit radio waves (radio quiet quasars). *See also* 1963 AST.

Harold Weaver and coworkers discover the radio emission of OH radicals in certain galactic regions, which is caused by “cosmic masers.” Cosmic masers are regions in clouds of interstellar gas that are stimulated to produce radiation by starlight; the radiation produced is of the coherent type

most familiar today as the light from a laser. *See also* 1953 TOOL.

Astronomers at the Arecibo Ionospheric Observatory in Puerto Rico discover that the rotation of Venus is retrograde; that is, Venus rotates in a different direction from the other planets, so on Venus the Sun rises in the west and sets in the east; the period is approximately 247 days. They also discover that Mercury rotates on its axis with a period of about 59 days. Previously scientists believed that Mercury kept one face toward the Sun as the Moon does toward Earth.

Mariner IV reaches the neighborhood of Mars on July 15, passing within 12,000 km (7500 mi) of the planet.

The Russian space probe *Zond III* photographs areas on the far side of the Moon that had not been previously photographed by the probe *Lunik III*. *See also* 1959 AST.

On November 16 the Soviet Union launches *Venera 3*, the first space probe to make physical contact with another planet, crash-landing on Venus; radio contact is lost before it reaches the immediate vicinity of the planet.

The United States launches *Pioneer 6* into the solar orbit on December 16. It will continue to function to this day, although it will not be tracked for data purposes after 1995. However, it will be contacted successfully on December 8, 2000, to mark its 35th anniversary in space.

Biology

W.A. Jones, Morton Beroza, and Martin Jacobson develop artificial sex attractants, or pheromones, for cockroaches

and other insects. *See also* 1958 BIO.

British scientist Alec D. Bangham and coworkers show that phospholipid bilayers form closed spheres in water; such bilayers are typical of the cell membrane, which makes this discovery of theoretical importance. Later such phospholipid spheres will be used in practical applications, such as delivering drugs to a specific target.

William J. Dreyer [b. 1928] and J. Claude Bennet [b. Birmingham, Alabama, December 12, 1933] propose that antibodies can match many different antigens because they have many variable genes and a single constant gene. This basic concept is later proved correct, although much more complex than in Dreyer and Bennet's original proposal. *See also* 1961 MED; 1967 MED.

Robert Holley in March works out the complete structure of a molecule of transfer-RNA, the molecule that builds proteins based on instructions from DNA. *See also* 1961 BIO; 1967 BIO.

Hans Ris and Walter Plaut discover that chloroplasts in algae — the small cell organelles where photosynthesis takes place — have their own DNA.

Bengt I. Samuelsson [b. Halmstad, Sweden, May 21, 1934], who had with Sune Bergström in the period 1959–62 advanced elucidation of the role of prostaglandins, discovers that important precursors, the endoperoxides, also have significant biological roles. His continuing work will show that thromboxanes and leukotrienes are also part of this system. *See also* 1982 BIO.

French biologists François Jacob, Jacques Monod, and André-Michael Lwoff win the Nobel Prize for physiology or medicine for their studies and discoveries on the regulatory activities of genes. *See also* 1960 BIO; 1953 BIO.

Chemistry

Robert Woodward of the United States wins the Nobel Prize in chemistry for the synthesis of organic compounds. *See also* 1951 CHEM.

Communication

Early Bird (Intelsat 1), the first commercial communications satellite, goes into geosynchronous orbit (an orbit that maintains the satellite above the same region of Earth's surface at all times) in April. Launched by the United States for the Communications Satellite Corporation (COMSAT), *Early Bird* can relay 240 telephone conversations simultaneously (or one television channel). *See also* 1964 COMM.

On April 23 the Soviet Union launches *Molniya I*, the first Soviet communications satellite. *See also* 1964 COMM.

The first portable consumer video recorder, including camera, is introduced by Sony. *See also* 1956 COMM; 1971 COMM.

Theodore Nelson develops hypertext, a text processing and organizing system that stores text as an interconnected whole, with linkages that allow rapid access to any part of the stored material.

Niklaus Wirth [b. Winterthur, Switzerland, February, 1934] develops the computer language Euler. *See also* 1970 COMM.

Joseph Weizenbaum [b. Berlin, January 8, 1923] at MIT develops ELIZA, a computer program for the study of natural language communication between man and machine. The program can carry on a conversation, questioning the user about his or her psychological problems (the first description will be published in January 1966). *See also* 1968 COMP.

Computers

Digital Equipment Corporation, or DEC, introduces the PDP-8 (Programmed Data Processor), the first minicomputer, which, compared with the mainframe computer, is simple to operate and low cost (\$18,000). It has 4K of ferrite core memory. The introduction of minicomputers is the beginning of widespread computerization of business and education. *See also* 1953 COMP.

Burroughs, implementing a design from a team led by Dan Slotnick [b. New York City, November 12, 1931, d. October 25, 1985], develops the ILLIAC IV (Illinois Automatic Computer), the first computer to use a parallel, non-von Neumann design (later known as "massively parallel architecture"). It has 64 identical scalar computers operating in parallel. Later, massively parallel computers will use microprocessors instead of separate computers. *See also* 1967 COMP.

Earth science

J. Tuzo Wilson publishes *A New Class of Faults and Their Bearing on Continental Drift*, one of the first works to combine sea-floor spreading and continental drift into the theory that becomes plate tectonics. Wilson suggests that faults

perpendicular to the mid-ocean rifts develop as the sea-floor spreads. Such transform faults are found to be characteristic of sea-floor spreading. *See also* 1963 EAR; 1986 EAR.

The U.S. navy's *Sealab II* project concludes after 45 days; during the project, people live in the sea off the coast of California at a depth of 62 m (205 ft).

Melvin Calvin and coworkers discover the breakdown products of chlorophyll in the Soudan shale of Minnesota, a rock formation that is between 2,500,000,000 and 2,900,000,000 years old. This implies that oxygen-producing organisms were in existence at that early time. *See also* 1954 EAR; 1968 EAR.

❖ Ecology & the environment

The U.S. Congress passes the Highway Beautification Act, restricting advertising visible to drivers on U.S. highways. *See also* 1964 ECOL; 1966 ECOL.

▀ Electronics

Gordon Moore formulates the law named after him: The number of transistors that can be placed on a microchip doubles every year. Moore's law, modified later to predict doubling every 18 months instead of every year, will remain valid as modified into the beginning of the 21st century. *See also* 1959 ELEC.

Chip designers produce chips with a component density of 1000 per square cm (middle scale integration or MSI). *See also* 1961 ELEC; 1973 ELEC.

↗ Energy

A chain reaction from a faulty relay in a Canadian hydroelectric plant knocks out the

power for 14 hours in New York City and in much of the northeastern United States and southern Canada on November 9.

The first practical application of fuel cells begins. They are used for on-board power in the U.S. piloted space program, beginning with the Gemini missions. Fuel cells will later be the on-board energy source for the Apollo series of Moon missions and in the space shuttles. *See also* 1959 ENER.

▀ Food & agriculture

The artificial sweetener aspartame, eventually marketed as NutraSweet in the United States, is invented at the Searle Laboratory in the United States. *See also* 1950 FOOD.

◊ Materials

James M. Faria and Robert T. Wright of Monsanto Industries co-invent AstroTurf, a sort of artificial grass made mainly from nylon. A patent for AstroTurf is filed for on December 25. AstroTurf is used to cover the football playing field at the Astrodome in Houston, Texas, which opens in 1966. In subsequent years, most new and some existing football and baseball fields will use similar artificial turf as a playing surface. *See also* 1935 MATR.

Royal Crown (RC) Cola becomes the first soft drink to use aluminum cans. *See also* 1963 FOOD.

Karl Stetson and Robert Powell of the University of Michigan use the principle of holography in a method that reveals defects in materials in a nondestructive manner, called time averaged interfer-

ometry. This process will become the principal industrial application of holography. *See also* 1947 COMM.

Σ Mathematics

Lotfi Zadeh defines "fuzzy sets" by combining elements of set theory with principles of "multivalued logic" first established by Jan Lukasiewicz in the 1920s. Fuzzy logic will be applied in control technology and forms the base of the FUZZY language. *See also* 1985 ELEC.

Hugh C. Williams, R.A. German, and C. Robert Zarnke use an IBM 7040 to calculate the first exact solution to Archimedes' "Cattle of the Sun" problem, posed about 2000 years earlier. The number describing the total number of cattle has 205,545 digits and the complete number will not be published until years later. *See also* 1773 MATH.

♥ Medicine & health

Psychologist Harry Harlow [b. Fairfield, Iowa, 1905, d. 1981] demonstrates that monkeys reared in total isolation show great emotional impairment for the rest of their lives.

Morris E. Davis reports that estrogen therapy prevents atherosclerosis and osteoporosis in postmenopausal women (later discredited). *See also* 1941 MED.

On July 13 Benjamin A. Rubin [b. New York, September 27, 1917] patents the bifurcated vaccination needle, useful mainly for delivering smallpox vaccine in small doses with little difficulty. The needle becomes one of the main tools used in the worldwide eradication of the disease.

Soft contact lenses are invent-

ed. *See also* 1958 MED; 1988 MED.

❖ Physics

Moo-Young Han [b. 1934] and Yoichiro Nambu introduce the SU(3) concept for quarks that is later named color symmetry. Their theory becomes known as quantum chromodynamics. *See also* 1972 PHY.

Nicolaas Bloembergen [b. Dordrecht, Netherlands, March 11, 1920] publishes *Nonlinear Optics*, based on the work with lasers that his group at Harvard University has been doing since 1961. Their studies give a theoretical background to how light interacts with matter based on laser spectroscopy. *See also* 1981 PHY.

Julian Schwinger and Richard Feynman of the United States and Shin'ichiro Tomonaga of Japan win the Nobel Prize in physics for their research into the basic principles of quantum electrodynamics. *See also* 1948 PHY; 1943 PHY.

▀ Tools

Joseph Giordmaine and Robert C. Miller at Bell Laboratories develop the continuously tunable laser. *See also* 1962 TOOL; 1970 TOOL.

Cambridge Instrument Company announces the first commercially available scanning electron microscope, based on the device developed in 1944 by Charles Oatley. It produces images that seem almost three dimensional by scanning and capturing surface features. *See also* 1947 TOOL.

↗ Transportation

Virgil Grissom and John W. Young [b. San Francisco, Sep-

tember 24, 1930], the first American multiperson space crew, are launched on the three-orbit *Gemini 3* mission on March 23. Astronauts James A. McDivitt [b. Chicago, Illinois, June 10, 1929] and Edward H. White II [b. San Antonio, Texas, November 14, 1930, d. Cape Canaveral, Florida, January 27, 1967] complete the first American extravehicular activity (EVA, or “space-walk”) and the first use of a personal propulsion unit during the 62-orbit *Gemini 4* mission that begins on June 3. Astronauts L. Gordon Cooper and Charles Conrad, Jr. [b. Philadelphia, Pennsylvania, June 2, 1930, d. Ojai, California, July 8, 1999] begin a 120-orbit *Gemini 5* mission on August 21; this demonstrates the feasibility of a lunar mission and is a simulated rendezvous. Astronauts Frank Borman [b. Gary, Indiana, March 14, 1928] and James A. Lovell, Jr. [b. Cleveland, Ohio, March 25, 1928] are launched on December 4 to start the 206-orbit *Gemini 7* mission, extending testing and performance goals for a lunar flight, as well as becoming the target for the first U.S. space rendezvous, with the *Gemini 6A* mission. Astronauts Walter Schirra and Thomas P. Stafford [b. Weatherford, Oklahoma, September 17, 1930] complete the first space rendezvous, with *Gemini 7*, during the 15-orbit *Gemini 6A* mission, launched on December 15.

Soviet cosmonauts Aleksei A. Leonov [b. Listvyanka, Russia, May 30, 1934] and Pavel I. Belyayev [b. Chelizshevo, Russia, June 26, 1925, d. January 10, 1970] begin the 17-orbit *Voskhod 2* mission, which lasts 26 hours, on March 18;

Leonov achieves the first extravehicular activity (or “spacewalk,” a trip outside a satellite wearing only a spacesuit), lasting 20 minutes.

On July 16 the Soviet Union launches *Proton I*. At 12,200 kg (26,896 lb) it is the largest Earth satellite to date.

On November 26 France launches *A-1*, the first satellite launched by a nation other than the Soviet Union or the United States.

Ford invents the sodium-sulfur electric battery for use in automobiles; although it is lighter and more powerful than conventional lead-acid batteries, it is also much more expensive to manufacture. See also 1900 ENER; 1991 ENER.

1966

► Anthropology

The Territorial Imperative by Robert Ardrey [b. Chicago, Illinois, October 16, 1908, d. January 14, 1980] argues that human beings, like songbirds and other animals, are naturally territorial. Another popular book, *On Aggression* by Konrad Lorenz, claims that only human beings intentionally kill members of their own species. See also 1973 ECOL.

★ Astronomy

British Astronomer Royal Sir Martin Rees [b. June 23, 1942] discovers quasars whose components seem to separate from each other at velocities greater than the velocity of light; the phenomenon will later be explained as caused by the light heading at a small angle toward the observer, giving an illusion of greater speed. See also 1963 AST; 1980 AST.

Allan Sandage identifies a visual star with the X-ray source Sco X-1, a bright X-ray star that mysteriously varies by as much as 250 percent within a few days. See also 1962 AST; 1970 AST.

On January 31 the Soviet Union launches *Luna IX*; although its main vehicle crash-lands, the ejected capsule lands nondestructively and transmits photographs to Earth from the Ocean of Storms. On March 31 the Soviets launch *Luna X*, the first space vehicle to go into orbit about the Moon. In August Soviet space probe *Luna XI* also goes into orbit around the Moon. Soviet space probe *Luna XIII* lands on the Moon and returns photographs and data about soil.

The Soviet Union’s space probe *Venera 3* becomes the first object made by humans to land on another planet when it reaches Venus on March 1.

Surveyor I is launched by the United States on May 30. On June 1 it lands on the Moon in the Ocean of Storms and returns pictures of the lunar surface to Earth. U.S. spacecraft *Lunar Orbiter I*, designed to send back photographs of the Moon from orbit about it, begins operation on August 10; although one of its cameras fails, it returns dramatic photographs of the Moon’s surface, including the far side, to Earth. A second *Lunar Orbiter* is launched by the United States on November 6; it is even more successful than the first.

↗ Biology

Marshall Nirenberg and coworkers crack the genetic code, proving that a sequence

of three nucleotides determines each of 20 amino acids — a concept first advanced by George Gamow. See also 1961 BIO; 1968 BIO.

Sol Spiegelman and Ichiro Haruna discover an enzyme that allows RNA molecules to duplicate themselves.

□ Chemistry

Robert Sanderson Mulliken wins the Nobel Prize in chemistry for his study of atomic bonds in molecules. See also 1947 CHEM.

☛ Communication

Donald W. Davies [b. Treorchy, England, June 7, 1924, d. Australia, May 28, 2000] at the National Physical Laboratory in Great Britain coins the term *packet switching* to describe the new way he and coworkers have developed, independently of similar work by Paul Baran earlier, to trade information over a computer network. Packet switching becomes the basis of the Internet. See also 1964 COMM; 1969 COMM.

Charles K. Kao [b. Shanghai, China, November 1933] and George Hockham of Standard Telecommunications Laboratories in England demonstrate that fibers of very pure glass can be used for the transmission of light carrying data over long distances, replacing traditional copper wire and electric currents for this purpose. See also 1955 COMM; 1977 COMM.

⊕ Earth science

Richard G. Doell, G. Brent Dalrymple, and Allan Cox [b. Santa Ana, California, December 17, 1926, d. Stanford, California, January 27, 1987]

study lava from ancient volcanoes, establishing that Earth's magnetic field has undergone periodic reversals in which the north and south magnetic poles are interchanged and determining the lengths of time between reversals. *See also* 1963 EAR.

On February 3 the United States Environmental Science Services Administration launches *ESSA I*, the first weather satellite capable of viewing the entire Earth. It is based on the spin-scan concept invented by Verner Suomi. *See also* 1964 EAR.

Ecology & the environment

Robert Paine [b. Cambridge, Massachusetts, April 13, 1933] of the University of Washington, Seattle, shows that biological diversity on rocky shores of the Pacific in Washington State is promoted by a brightly colored starfish (*Pisaster ochraceus*) that preys on mussels. Removing the starfish from a section of the shore soon results in the loss of sea anemones, limpets, and barnacles, all of which are replaced by mussels. Paine coins the term "keystone species" to describe the role of the starfish, and the concept will become one of the basic tenets of ecology during the remainder of the century.

The U.S. Congress passes the Rare and Endangered Species Act, setting up rules by which the Fish and Wildlife Service can list and protect species in danger of extinction. *See also* 1965 ECOL; 1967 ECOL.

Energy

The world's largest electricity plant using tidal power, the

Rance Tidal Works, is installed near the mouth of the Rance River on France's Channel coast (near the isle of Jersey); a dam 750 m (2500 ft) long contains 24 turbines and generators that produce a total of 240 megawatts of electric power. *See also* 1968 ENER.

Medicine & health

(Daniel) Carleton Gajdusek [b. Yonkers, New York, September 9, 1923] succeeds in transferring kuru, a disease of the central nervous system thought to be spread by cannibalism, to chimpanzees, the first time a viral disease of the central nervous system is transferred from humans to another species. *See also* 1982 MED.

In May Michael B. Sporn, C. Wesley Dingman, Hariette L. Phelps, and Gerald N. Wogan report that aflatoxins caused by the mold *Aspergillus flavus* growing on peanuts cause liver damage and cancer.

Charles Huggins and Francis Peyton Rous of the United States win the Nobel Prize for physiology or medicine for their research on the treatment and causes of cancer. *See also* 1941 MED; 1910 MED.

Physics

Richard Robert Ernst [b. Winterthur, Switzerland, August 14, 1933] and Weston A. Anderson develop the basic method of nuclear magnetic resonance spectroscopy, in which materials that contain nuclei with a magnetic moment are placed in a magnetic field and excited by a pulse of radio waves. The electromagnetic frequencies emitted when these nuclei fall back into the ground state are measured and used to determine properties of nuclei and

identities or locations of specific elements. *See also* 1971 MED; 1991 CHEM.

The Committee on Data for Science and Technology (CODATA) is established to determine internationally accepted values for all fundamental physical constants. *See also* 1960 COMM; 1967 COMM.

Alfred Kastler of France wins the Nobel Prize in physics for his study of atomic structure by optical pumping. *See also* 1950 TOOL.

Tools

The SLAC (Stanford Linear Accelerator Center) particle accelerator goes into operation. *See also* 1954 TOOL; 1972 TOOL.

An all-time height record for a gunpowder-powered missile is set on November 19 by the U.S. Defense Department's High Altitude Research Program (HARP); the HARP gun fires a 94 kg (185 lb) projectile to an altitude of 180 km (111.8 mi).

Arthur Minasy [b. 1926, d. 1994] invents the magnetic store tag, a device embedded in plastic that protects items from shoplifting. The tag is attached to the item and removed by a salesperson at the point of sale; if the tag is not removed and passes through detectors at the exit from the store, an alarm is sounded.

Transportation

On March 16 Neil Alden Armstrong [b. Wapakoneta, Ohio, August 5, 1930] and David R. Scott [b. San Antonio, Texas, June 6, 1932] lift off in a *Gemini 8* spacecraft as part of the first American dual launch and docking with a target vehicle.

The mission concludes with the first Pacific Ocean splashdown after 6.5-orbits. On June 3 astronauts Thomas Stafford and Eugene A. Cernan [b. Chicago, Illinois, March 14, 1934] begin the 44-orbit *Gemini 9A* mission. Although they are unable to dock with the target vehicle, they succeed in conducting 2 hours, 7 minutes of extravehicular activity (EVA). On July 18 astronauts John Young and Michael Collins [b. Rome, Italy, October 31, 1930] begin the 43-orbit *Gemini 10* space mission, which will feature the first dual rendezvous and docked vehicle maneuvers with umbilical EVA. On September 12 astronauts Charles Conrad and Richard F. Gordon, Jr. [b. Seattle, Washington, October 5, 1929] are launched on the 44-orbit *Gemini 11*, practicing rendezvous and docking maneuvers in space. On November 11 astronauts James Lovell and Edwin A. "Buzz" Aldrin [b. Montclair, New Jersey, January 20, 1930] are launched on the final Gemini mission, lasting 59 orbits and including 5 hours of EVA.

Fuel injection for automobile engines is developed in the United Kingdom. *See also* 1893 ENER.

1967

Anthropology

British archaeologists J.R. Cann, J.E. Dixon, and Colin Renfrew [b. July 25, 1937] announce that a study of obsidian from various Neolithic (New Stone Age) sites establishes that complex trade routes existed in the Mediterranean basin in the period between 8000 BCE and 5000 BCE. *See also* 11,000 BCE TRAN.

Geoscientist Paul Martin proposes that human hunters who traveled into North America some 11,000 years BP killed so many large animals and birds (known as the megafauna) that these became extinct. This theory comes to be known as the blitzkrieg hypothesis for megafaunal extinction. *See also* 11,500 BCE TOOL.

▲ Archaeology

Greek seismologist Angelos Galanopoulos suggests that a great volcanic explosion that nearly destroyed the island of Thera (also known as Santorini) gave rise to the myth of Atlantis. Greek archaeologist Spyridon Marinatos [b. November 4, 1901, d. October 1, 1974] discovers the ruins of Akrotiri, a Bronze Age city, on the island of Thera. *See also* 1645 BCE EAR.

★ Astronomy

Jocelyn Bell (later Bell Burnell), using a new radio telescope designed by Anthony Hewish, observes the first pulsar, CP 1919 ("Cambridge pulsar right ascension 19 hr 19 min") in July in the constellation Velpecula. At first the pulsar's regular signal is taken to be a message from extraterrestrial beings, or "little green men," but soon Thomas Gold will show that the signal is caused by a neutron star rotating very fast. Bell's supervisor, Anthony Hewish, will be given a share of the 1974 Nobel Prize for this discovery. Because they do not know the origin of the signals, data on the pulsar are not published until February 1968. *See also* 1968 AST.

At a meeting of the Institute for Space Studies in New York, John Archibald Wheeler [b.

1911] uses the term "black hole" to describe a gravitationally collapsed star from which no light can escape because the star's mass becomes concentrated in too small a region of space. *See also* 1939 AST; 1974 AST.

William A. Fowler [b. Pittsburgh, Pennsylvania, August 9, 1911, d. Pasadena, California, March 14, 1995], Robert Wagoner, and Fred Hoyle show that the atomic nuclei of hydrogen, deuterium, helium, and lithium are formed shortly after the big bang, but no other nuclei. All heavier nuclei are formed in nuclear reactions in stars. *See also* 1974 AST.

U.S. space probe *Surveyor III* soft-lands on the Moon on April 19. The robot craft digs small trenches in the lunar surface and returns photographs of the results to Earth, where the lunar soil is thought (incorrectly) to look a lot like Earth soil and therefore be safe to walk upon (which is correct). *Surveyor V* soft-lands on the Sea of Tranquility September 10. *Surveyor VI* soft-lands on Central Bay on the Moon November 9.

The Soviet space probe *Venera 4* parachutes a capsule into the atmosphere of Venus, where high pressures and temperatures cause it to cease functioning about the time it is thought to have hit the surface of the

planet; telemetry from its descent reveals that the atmosphere of Venus is mostly carbon dioxide.

The third U.S. *Lunar Orbiter* completes the task of surveying possible landing sights on the Moon for the Apollo astronauts. U.S. scientists launch *Lunar Orbiter IV* on May 4. Its mission is to map the face of the Moon in more detail than can be seen from telescopes placed on Earth.

Launched on June 14, U.S. space probe *Mariner V* flies to within 4000 km (2600 mi) of Venus. It obtains data on the atmosphere, temperature, and air pressure of Venus that are roughly consistent with the *Venera* probe of the previous day. Later data will show, however, that the temperature and pressure are even higher than recorded.

Hans Bethe of the United States wins the Nobel Prize in physics for his study of the energy production of stars. *See also* 1938 AST.

❖ Biology

Allan M. Campbell discovers that some circular bits of material called plasmids resembling chromosomes carry genetic information from one bacterium to another. Plasmids often transmit an ability to resist antibiotics and other bacterial poisons. *See also* 1964 BIO.

Charles Yanofsky and coworkers demonstrate that the sequence of codons in a gene determines the sequence of amino acids in a protein. Although this relationship had been previously assumed, Yanofsky's work was the first to show that it definitely occurs. *See also* 1965 BIO.

Charles Thomas Caskey, Richard E. Marshall, and Marshall Nirenberg show that identical forms of messenger RNA are used to produce the same amino acids in bacteria, guinea pigs, and toads, suggesting (correctly) that the genetic code is a universal system used by all life forms. *See also* 1965 BIO.

Arthur Kornberg announces that he and coworkers have synthesized biologically active DNA. Specifically, they used one strand of natural DNA from a virus as a template to assemble the paired strand from laboratory chemicals. *See also* 1957 BIO; 1970 BIO.

Sydney Brenner, Francis Crick, and colleagues decode another genetic codon on DNA that signals a stop message; this nearly completes the decoding of the various DNA codons. *See also* 1966 BIO; 1968 BIO.

Alf Erling Porsild [b. 1901, d. 1977] and Charles R. Arington announce in October that they have grown arctic lupines from seeds that had been frozen

(Susan) Jocelyn Bell Burnell (a.k.a. Jocelyn Bell)

[b. Belfast, Northern Ireland, July 15, 1943]

As a graduate student surveying quasars with a radio telescope at Cambridge University in England she had helped build, Bell recognized that a periodic radio signal had too short a period and was too regular to come from any then known astronomical phenomenon. After a brief period during which Bell and Anthony Hewish suspected extraterrestrial life as a source and Bell discovered a second similarly periodic signal, the sources were named pulsars. Bell then discovered two more pulsars, all of which would later be recognized as neutron stars. Her later work used satellites and radio telescopes to study stars and other astronomical bodies at almost all electromagnetic wavelengths.

since the last Ice Age, setting a new record of about 10,000 years for the length of time that plant seeds can remain viable under proper conditions.

Haldan Keffer Hartline, George Wald, and Ragnar Arthur Granit win the Nobel Prize for physiology or medicine for their advanced discoveries in the physiology and chemistry of the human eye. *See also* 1949 BIO; 1933 BIO; 1947 BIO.

Chemistry

Scientists at the Dubna Institute in Russia create element 105, dubnium (Db), by shooting neon ions at a target of americium.

John C. Polanyi [b. Berlin, 1929] develops the method of infrared chemiluminescence for studying chemical reactions and bonds. *See also* 1986 CHEM.

In October, Jean-Marie Lehn [b. Rosheim, France, September 30, 1939] begins a line of study aimed at finding chemical substances that will make membranes permeable to cations, which leads to the design of cation cryptates, later developing into the new field of supramolecular chemistry. *See also* 1987 CHEM.

Manfred Eigen, Ronald G.W. Norrish, and George Porter share the Nobel Prize in chemistry for their study of high-speed chemical reactions. *See also* 1960 CHEM; 1947 CHEM.

Communication

Hell Digiset and RCA Video-com introduce photocomposition machines that use cathode-ray tubes to form letters. *See also* 1949 COMM.

Ray Milton Dolby [b. Portland, Oregon, January 18,

1933] develops a method to eliminate background sound in recordings. "Dolby sound" also improves fidelity in other ways and it becomes a standard feature on many recorded music players as well as for motion pictures. *See also* 1958 COMM.

The General Conference of Weights and Measures in Sèvres, France, redefines the second, which had been based on the rotation of Earth, in terms of the transition level between the two lowest levels of cesium as measured by an atomic clock. Specifically, the second is the amount of time corresponding to 9,192,631,770 cycles of the electromagnetic wave tuned to the cesium atom's transitions. *See also* 1889 COMM; 1983 COMM.

Computers

Olof Soderblom introduces the concept of a computer network in which computers are connected to a closed loop rather than a centralized system. This concept will be used by IBM as the design of its networked computer systems.

Gene Amdahl proposes the construction of a computer with parallel processors. Such a machine would be able to solve certain classes of problems much faster than an ordinary computer, which always works in a linear sequence. *See also* 1965 COMP; 1983 COMP.

Earth science

British geophysicists Dan McKenzie [b. Cheltenham, England, February 21, 1942] and Robert L. Parker propose that Earth's crust consists of rigid, mobile plates — a theory now central to geology. In April William Jason Morgan of Princeton University intro-

duces for the first time the full concept of plate tectonics at an American Geophysical Union meeting. *See also* 1960 EAR.

The three-person submersible *Alvin*, which can dive to 4500 m (15,000 ft) and explore as much as 62 percent of the ocean's floor, begins operations. *See also* 1964 EAR.

Ecology & the environment

The Theory of Island Biogeography by Robert MacArthur and Edward O. Wilson is the beginning of equilibrium biogeography, a school of ecology that focuses on situations where systems are in balance and therefore stable. Their studies demonstrate that island ecosystems settle into an equilibrium state, losing some species while gaining others, but maintaining the same overall diversity. *See also* 1958 ECOL.

Syukuro Manabe [b. Shingu-Mura, Japan, September 21, 1931] and Richard T. Wetherald warn that human activities that increase the amount of carbon dioxide in the air, such as the burning of fossil fuels, are causing a greenhouse effect that will raise global temperatures. *See also* 1938 EAR; 1968 ECOL.

The Deer and the Tiger by George Schaller [b. Berlin, 1933] describes the interactions between tigers and their prey in India. It is the first major study of predator-prey relations for large mammals.

Energy

Project Gasbuggy, part of Project Plowshare of the U.S. Atomic Energy Commission, explodes a nuclear charge underground near Farmington, New Mexico, in hopes of

stimulating production of natural gas. This attempt and a similar one two years later both fail. *See also* 1962 ENER.

Food & agriculture

The U.S. Department of Agriculture starts a test project in irradiating wheat and other foods to kill insects. *See also* 1898 FOOD; 1968 FOOD.

The National Academy of Sciences in June reports that the practice of adding antibiotics to animal food, while producing greater yields, may leave traces in meat and also may increase drug resistance in bacteria. *See also* 1959 BIO.

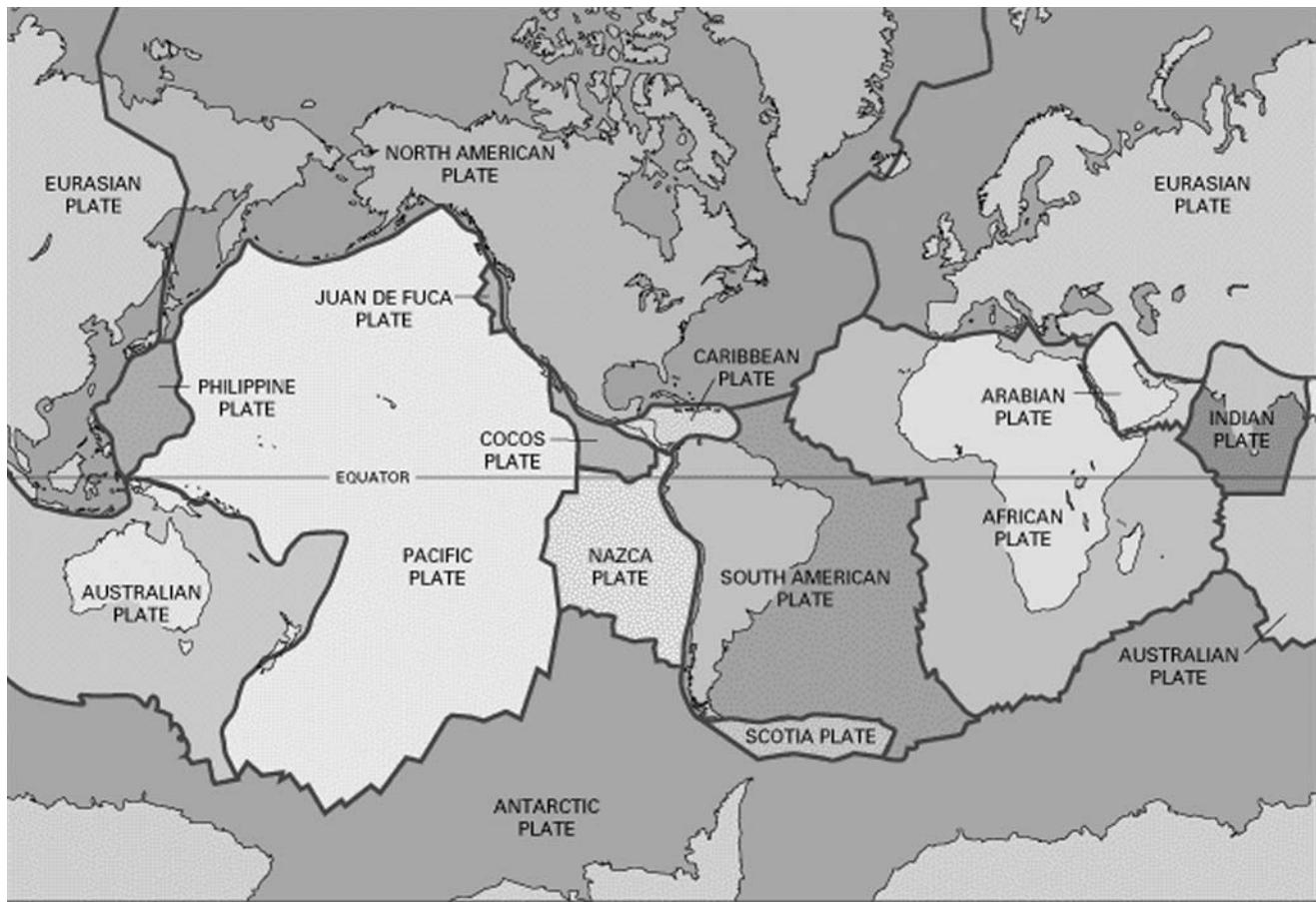
Using an improved electron tube introduced in Japan, Raytheon introduces the first small, affordable microwave oven. *See also* 1955 FOOD.

Materials

When a visitor from Korea accidentally adds too much catalyst to an experiment that polymer physicist Hideki Shirakawa [b. Tokyo, August 20, 1936] is performing, the first polyacetylene film emerges. This form of polyacetylene has metallic properties, such as shiny surfaces and a small degree of electric conductivity. *See also* 1976 MATR.

Medicine & health

Surgeon Christiaan Neethling Barnard [b. Beaufort, South Africa, November 8, 1922, d. Paphos, Cyprus, September 2, 2001] performs the first partially successful human heart transplant on December 3. The recipient of the new heart is Louis Washkansky [b. Lithuania, 1913, d. Capetown, South Africa, December 21, 1967], who lives for 18 days. *See also* 1963 MED; 1968 MED.



MAP OF EARTH'S TECTONIC PLATES Not all the plates shown here were recognized at first — such smaller plates as the Juan de Fuca, Cocos, Nazca, Scotia, and even the Indian plate had not yet been identified in the late 1960s. Exploration of undersea mountain and rift belts has been the principal means of identification. Each of the tectonic plates is in motion, slowly moving toward or away from or slipping past each other.

George Davis Snell [b. Bradford, Massachusetts, December 19, 1903, d. Bar Harbor, Maine, June 6, 1996] discovers that tissue compatibility is determined by specific genes. *See also* 1961 MED; 1980 MED.

In Cleveland surgeon Rene Favaloro [b. Argentina, July 12, 1923, d. Buenos Aires, July 29, 2000] develops the coronary bypass operation. *See also* 1953 MED.

Bonding using composite resins is developed as an alter-

native to filling teeth with metal alloys. *See also* 1952 MED.

Sidney Cohen [b. Boston, Massachusetts, June 15, 1918, d. 1987] and coworkers report that LSD (lysergic acid diethylamide), frequently taken as a drug to induce an altered state of consciousness, produces breaks in chromosomes, creating the possibility of genetic abnormalities in children of LSD users. *See also* 1943 CHEM.

Australian Sir Gustave Joseph

Victor Nossal [b. 1931] proposes in June that antibodies work by detecting the size and shape of their target molecule so that they can attach themselves to the antigen. *See also* 1965 MED; 1987 BIO.

Clomiphene is introduced to increase fertility; it also results in an increase in multiple births. *See also* 1956 MED.

A 20-year study of fluoridation in Evanston, Illinois, shows that dental cavities have been reduced by 58 percent as a result of adding fluorides to

the water supply. *See also* 1874 MED; 1945 MED.

Mammography for detecting breast cancer is introduced. *See also* 1896 MED.

Michael S. Gazzaniga reports that studies of people whose brain halves have been severed reveal that the two halves function independently.

* Physics

Independently, Steven Weinberg [b. New York City, May 3, 1933], Abdus Salam, and Sheldon Glashow develop elec-

Plate tectonics

In 1912 Alfred Wegener, a German meteorologist, announced his belief in the idea of continental drift. Wegener was not the first to notice that the coastlines of South America and Africa seem to fit together as if they had once been part of a single continent that had broken apart. But he pursued the idea more vigorously than others had, gathering evidence that fossils and rock strata were the same on the two matching coasts. Most geologists rejected his evidence, however, because he could not suggest a workable way for the continents to move through the solid rock of Earth's crust. However, the theory was too appealing to be forgotten. After World War II, geology textbooks generally mentioned Wegener's theory of continental drift but also continued to cast doubt on its validity.

Beginning in the early 1950s, better equipment for measuring the residue of Earth's magnetism that is found in rocks, improved methods for measuring the age of rocks, and a program of exploration of the floor of the oceans all combined to vindicate partially continental drift. The new magnetic studies showed that rocks of the same age on different continents indicate that in the past the magnetic poles seemed to be in two places at the same time; that is, latent magnetism on one continent from a given time in the past pointed to a different location for the magnetic poles than similar magnetism on rocks of the same age on a different continent. The best explanation was that the continents had changed position with regard to each other.

It had been known since 1929 that the magnetic field of Earth reverses itself every few hundred thousand years. This had been observed in successive strata, one above the other, on the continents. In the early 1960s, Frederick Vine and Drummond

Matthews demonstrated that on the floor of the ocean these reversals do not occur in different strata vertically but instead lay in similar strata that are side by side. In effect, from a magnetic point of view, the rocks of the ocean floor are striped. The youngest stripes are immediately adjacent to a formation in the middle of the ocean, a valley with mountains on either side that is known as a rift valley. As one travels farther from the mid-ocean rift, the rocks are older. This tends to confirm a 1960 theory of Harry Hess that new ocean crust is being formed at the rift. According to Hess's theory, the oldest crust should be sinking into deep trenches in the ocean floor, such as the one off the Philippine islands. This part of the theory, which came to be known as sea-floor spreading, was also confirmed by measuring the ages of rocks dredged from the ocean bottom.

Geologists synthesized continental drift and sea-floor spreading into a single theory, plate tectonics (tectonics means movements of Earth's crust). According to plate tectonics, the crust of Earth is broken into a number of large plates. Some of these plates contain only ocean crust, while others contain both continental crust and ocean crust. For example, one plate consists of most of the Pacific Ocean, while another contains North America and the western half of the Atlantic Ocean. These plates move through a partially fluid region of Earth just below the crust itself. Where the plates bump into each other, mountain ranges form. Most earthquakes and volcanoes are at the plate boundaries.

The theory was very successful at predicting many features of Earth's crust, but some geologists were not satisfied until the slow motion of the plates could be measured — typically about 2 cm (1 in.) per year. This was accomplished in the 1980s using satellites, lasers, and the positions of very distant galaxies.

tweak unification, which unifies the electromagnetic force and the weak interaction in terms of a spontaneously broken symmetry and group theory. The new theory predicts an observable transformation of particles, which physicists call the "neutral current," as well as the existence of mediating particles with masses greater than the mass of the proton. *See also* 1983 PHY.

Bern Matthias [b. Frankfurt, Germany, June 8, 1918, d. La Jolla, California, October 27, 1980] and coworkers find

an alloy of niobium, aluminum, and germanium that becomes superconducting at a temperature of 20.05 degrees Kelvin (-253.1°C or -423.6°F); this sets a record more than two degrees above the previous high temperature for superconductivity. *See also* 1911 PHY; 1986 PHY.

Russian physicist Vladimir Mikhailovich Lobashev [b. July 29, 1934] shows that the strong nuclear force also violates parity conservation (the P of the CPT theorem). *See also* 1964 PHY.

→ Transportation

U.S. astronauts Virgil Grissom, Edward White, and Roger B. Chaffee [b. Grand Rapids, Michigan, February 15, 1935, d. Cape Canaveral, Florida, January 27, 1967] die in a fire during a ground test of an Apollo spacecraft on January 27.

An 18-orbit *Soyuz 1* mission starts off on April 23, but Soviet cosmonaut Vladimir Komarov is killed on April 24 as he attempts an emergency re-entry from orbit. The parachute lines become entangled,

causing the craft to plunge to Earth.

The *Mutsu*, a nuclear-powered ship, is launched in Japan; however, it remains immobilized by Japanese fishermen for about two years because of their fear of nuclear contamination. In fact, nuclear leaks will occur when the ship starts operating. *See also* 1962 TRAN.

The tanker *Torrey Canyon* runs aground near the Cornish coast in England, in one of the worst ecological disasters, spilling over 119,000 tons of oil into the sea. *See also* 1969 ECOL.

Unifying the forces

Most physical theories aim at explaining apparently different phenomena by simple sets of laws. The best example is Newton's theory of gravitation. Apparently unrelated phenomena, such as the apple falling from the tree and the Moon circling Earth, are explained by a unique force: gravity. Gravity is a force that all masses exert on each other. It is an extremely weak force and can only be experienced when at least one of the masses is very large, such as Earth.

When scientists started experimenting with electricity and magnets they discovered other forces that seemed to act independently from gravitation: the magnetic force and the force of attraction or repulsion between electrically charged bodies. The two might be thought of as reciprocals, since electric charge produces magnetism and magnetism produces charge. When he developed his electromagnetic theory, James Clerk Maxwell unified these forces into one: the electromagnetic force. Charge and magnetism become two aspects of a single underlying reality.

In this century the study of the atomic nucleus has revealed two other forces in addition to gravity and electromagnetism. The strong force holds the protons and neutrons in the atomic nucleus together, and the weak force is responsible for certain slow nuclear processes, such as some types of radioactive decay.

With these four forces physicists can describe the whole range of known physical processes, and therefore these forces are called fundamental forces. The gravitational and electromagnetic forces are long-range forces because they act over the entire universe, while the weak and strong forces only act over very short distances. The forces act by means of particles, which are said to carry or to mediate the forces. Gravity and electromagnetism are mediated by massless particles, which is why they affect suitable bodies at infinite distances. The strong force was described by Yukawa's theory of 1935 as acting through a medium-mass particle, or meson. This explains why it is only effective at short distances. (In a theory called quantum chromodynamics, the mesons of the strong force are a manifestation of an underlying color force, although this does not change anything about the way the strong force operates.)

In science, the fewer laws to explain phenomena the better. Although the four forces seem to act independently of each other, physicists have been searching for a way to put them into a single theory, so that each is a different manifestation of some underlying reality. Theories that would achieve this are called unification schemes. Albert Einstein, for example, was convinced that it would be possible to unify gravitation and electromagnetic forces. He spent much of his later years trying to find such a theory, but without success.

In 1967 Steven Weinberg, Abdus Salam, and Sheldon Glashow formulated a theory called electroweak theory that unifies the weak force and the electromagnetic force. According to this theory, the weak forces in atomic nuclei are mediated by three particles with even larger masses than the particles transmitting the strong force. The carriers of the weak force are the W^+ , W^- , and Z^0 particles with charges, respectively, of +1, -1, and zero. Masses must be high because the force operates at short distances only. In the Weinberg-Salam-Glashow theory, however, at very high energies there is just one electroweak force; but at lower energies, the high-mass W and Z particles and the massless photons separate, becoming carriers of two different forces. Experimental verification of the existence of the high-mass particles eluded high-energy physicists until 1983, when scientists at CERN (Centre Européen de Recherche Nucléaire), near Geneva, Switzerland, under the direction of Carlo Rubbia, discovered the W and Z particles in head-on collisions in a huge proton-antiproton collider.

Theories that would unify the electromagnetic force, the strong force, and the weak force are called grand unification theories, or GUTs. Theoretical physicists have been somewhat successful in developing GUTs, but there are several competing theories and no evidence as to which one might be correct. It is generally believed that it will be much more difficult to find a theory that unifies the four fundamental forces. A theory that would unify gravity with the other forces — a theory sometimes called supergrand unification, or SuperGUT, a.k.a. the Theory of Everything — still has to be worked out. A promising beginning has been made with the development of superstring theories that emerged during the 1980s.

1968

► Anthropology

John Desmond Clark [b. London, April 10, 1916, d. Oakland, California, February 14, 2002] proposes that stone tool industries be grouped into five "modes" that are descriptive rather than based on specific

sites. The system names are Mode I (simple flakes and cores); Mode II (flakes produced by direct percussion); Mode III (wide use of prepared cores); Mode IV (in which blades and burins are dominant); and Mode V (microliths).

★ Astronomy

R. V. E. Lovelace, J. M. Sutton, and H. D. Craft find a pulsar with a period of 0.033 seconds in the center of the Crab Nebula in Taurus, the site of the supernova of July 4, 1054. They do not, however, observe the pulsar optically. See also 1934 AST.

Michael Large, Alan Vaughan, and Bernard Mills identify the pulsar usually called the Vela pulsar because it is in the remnant of the Vela supernova, but officially PSR 0833-45. See also 1967 AST; 1977 AST.

George Clark, Gordon Garmire, and William Kraushaar report the discov-

ery, using NASA's third *Orbiting Solar Observatory*, of a gamma-ray background coming from the Milky Way Galaxy, especially from its center. *See also* 1962 AST.

Surveyor 7 becomes the first space vehicle to land undamaged on the Moon, coming down on the rim of Tycho crater January 9. From there it sends back 21,000 photographs of the lunar surface.

The Soviet spacecraft *Zond 5* becomes the first human-created object to travel around the Moon and return to Earth.

Biology

Werner Arber [b. Granichen, Switzerland, June 3, 1929] discovers that bacteria defend themselves against viruses by producing enzymes that randomly cut the DNA of the virus. They are termed *restriction enzymes*. *See also* 1978 BIO.

David Zipser discovers the meaning of the only unknown codon of the 64 that make up the genetic code. It is the three-base codon UGA (for uracil, guanine, adenine) and Zipser discovers it to be a termination signal whose meaning is "stop making this protein." *See also* 1967 BIO.

Mark Ptashne and, independently, Walter Gilbert [b. Boston, Massachusetts, March 21, 1932] and their coworkers identify the first repressor proteins for genes, which prevent genes from operating. *See also* 1969 BIO.

David Hunter Hubel [b. Windsor, Ontario, Canada, February 27, 1926], and Torsten Nils Wiesel [b. Uppsala, Sweden, June 3, 1924] complete a program of ten years of research into the visu-

al receptors of the brain (mainly working with cats). They discover that specific cells respond to specific stimuli, such as stationary light sources for some and motion for others. *See also* 1981 BIO.

Robert Holley, Har Gobind Khorana, and Marshall Nirenberg of the United States win the Nobel Prize in physiology or medicine for understanding and deciphering the genetic code that determines cell function. *See also* 1965 BIO; 1964 BIO; 1966 BIO.

Chemistry

Edward Feigenbaum [b. Weehawken, New Jersey, January 20, 1936] at Stanford and geneticist Joshua Lederberg develop DENDRAL, an expert system using artificial intelligence for the identification of chemical substances based on the results of spectrometric analysis. *See also* 1959 COMM; 1972 COMM.

Lars Onsager of the United States wins the Nobel Prize in chemistry for his work on the theoretical basis of diffusion of isotopes. *See also* 1944 MATR.

Communication

Stephen Benton [b. San Francisco, California, 1941] develops the rainbow hologram, a hologram that can be embossed on a credit card or a magazine and that shows a three-dimensional image in ordinary light. Its name comes from the rainbow effect observed when viewed at different angles perpendicular to the left-right axis of the image. *See also* 1964 COMM.

Carl Englemann, William Martin, and Joel Moses develop the original specifications

for MACSYMA, a programming language that performs over 600 types of mathematical operations; it is accessible via the ARPA computer network. *See also* 1969 COMM.

Computers

Douglas Engelbart [b. Portland, Oregon, January 30, 1925] demonstrates during the autumn conference on computers in San Francisco the computer mouse, a device that moves the cursor (pointer) on a computer monitor and issues simple "execute" commands; the mouse is later adopted by Apple for the Lisa and Macintosh computers and then spreads throughout the industry. *See also* 1983 COMP.

Author Arthur Clarke writes *2001: A Space Odyssey*; the science-fiction novel features the computer Hal that understands the human voice and can converse with its operators. *See also* 1971 COMM.

Terry Winograd at MIT develops a complex expert system that incorporates reasoning capabilities. *See also* 1965 COMM; 1970 COMP.

Burroughs introduces the B2500 and B3500, the first computers incorporating integrated circuits. *See also* 1958 ELEC.

The Control Data Corporation launches the CDC 7600 supercomputer, designed by Seymour Cray, which is, with a speed of about 40 megaflops, to be the most powerful computer until the appearance of the Cray supercomputer in 1976. *See also* 1964 COMP; 1970 COMP.

Earth science

U.S. air force scientists show that radar can be used to

detect wind shifts and precipitation.

The U.S. research ship *Glomar Challenger* begins drilling cores out of ocean floor — long cylinders of ocean bottom whose sediments reveal the history of that part of the floor.

The *Glomar Challenger's Deep Sea Drilling Project* will obtain over 19,000 cores from the ocean floor in 96 legs (drilling runs) over the next 15 years. *See also* 1961 EAR; 1985 EAR.

Else Barghoorn and his coworkers report finding remains of amino acids in rocks that are as old as 3,000,000,000 years, indicating that life existed in that remote time. *See also* 1954 EAR.

Ecology & the environment

The U.S. Congress passes the Wild and Scenic Rivers Act, protecting parts of some rivers from commercial exploitation. *See also* 1967 ECOL; 1969 ECOL.

A report from the U.S. House of Representatives declares that Lake Erie is so polluted that it is essentially dead and that if all further pollution ceases it will take 500 years to restore it to its condition during World War II. *See also* 1960 ECOL.

Electronics

Gordon Moore and Robert Noyce, both leaving Fairchild Semiconductor, found Intel Corporation with the intention of manufacturing integrated circuits. *See also* 1957 ELEC; 1970 ELEC.

Energy

The Soviet Union opens an 800-kw tidal power station near Murmansk. *See also* 1966 ENER.

Food & agriculture

The Nuclear Materials Equipment Corporation begins sterilizing bacon and potatoes with radiation from radioactive cobalt-60 as a means of preserving them. James L. Goddard [b. Alliance, Ohio, 1923], commissioner of the U.S. Food and Drug Administration, refuses in April to permit canned ham that has been radioactively sterilized to be used for human consumption by the U.S. army. *See also* 1898 FOOD; 1967 FOOD.

Materials

A method for producing diamond from methane, later called chemical vapor deposition, is patented in the United States, but the diamond produced by the method is mixed with graphite, making it of limited use. *See also* 1954 MATR; 1981 MATR.

Mathematics

René Thom publishes the first paper describing catastrophe theory. *See also* 1972 MATH.

Medicine & health

Godfrey Hounsfield uses medical X rays to reconstruct a three-dimensional image, the essential development of the CT (CAT) scan, a method previously discovered by Allan Cormack and William Oldendorf. At this time the method cannot be used on living organisms, however. Unlike

Cormack and Oldendorf, Hounsfield finds medical personnel interested in pursuing the new method and continues to develop it. *See also* 1960 MED; 1971 MED.

English researchers report in April that oral contraceptives can cause blood clots in susceptible women. *See also* 1951 MED.

French-American physiologist Roger Guillemin [b. Dijon, France, January 11, 1924] and Polish-American biochemist Andrew Victor Schally [b. Vilna (Vilnius, Lithuania), November 30, 1926] discover in this year and the next a simple peptide (that is, a molecule consisting of amino acids, but too small to be called a protein), which they call CRF (corticotropin releasing factor). CRF is produced by the hypothalamus, a part of the brain, and it signals the pituitary gland to produce the hormone cortisol. *See also* 1930 MED; 1977 MED.

Christiaan Barnard performs a second human heart transplant; this time the patient, Philip Blaiberg, lives 563 days (nearly 19 months) with his new heart. *See also* 1967 MED; 1969 MED.

Dentists show that dental caries (tooth decay) is caused by a substance produced by streptococcal bacteria that normally live in the mouth when these bacteria metabolize sugar.

The U.S. government moves the people of Bikini island back to the atoll, claiming that radioactive contamination from the hydrogen bomb of 1956 has reached sufficiently low levels.

Doctors at the University of Minnesota perform the first successful bone marrow transplant to cure disease (other than radiation sickness) in a human being on a four-month-old boy suffering from an immune disorder, using marrow from his sister. *See also* 1956 MED.

Physics

French physicist Georges Charpak [b. Dabrovica, Poland, 1924] invents the multiwire proportional chamber, a particle detector that allows the determination of particle tracks in three dimensions with high precision. *See also* 1992 PHY.

Luis Alvarez of the United States wins the Nobel Prize in physics for his discovery of "resonance particles." *See also* 1960 PHY.

Transportation

The Soviet Soyuz 3 mission is launched on October 26 with cosmonaut Georgi Beregovoi [b. Fedorovka, Ukraine, April 15, 1921, d. June 30, 1995]. It approaches the unpiloted Soyuz 2 to a distance of 200 m (650 ft) and completes 64 orbits before landing.

Walter Schirra, Donn F. Eisele [b. Columbus, Ohio, June 23, 1930, d. Tokyo, December 2, 1987], and Walter Cunningham [b. Creston, Iowa, March 16, 1932] begin the Apollo 7 mission on October 11. The mission lasts 260 hours and features live TV sessions with crew and a rendezvous with a stage from the Saturn launch vehicle.

On December 21 the Apollo 8 mission is launched with Frank Borman, James Lovell, and William A. Anders [b. Hong Kong, October 17, 1933] as its crew. It is the first flight to be propelled by the *Saturn V* launch vehicle and the first time that humans are placed in orbit about the Moon. Apollo 8 completes 10 lunar orbits and returns good lunar photography (including much of the far side of the Moon not previously known) as well as photos of Earth from space. The crew broadcasts a Christmas Eve message on live television in which they take turns reading passages from the beginning of the Book of Genesis.

The first supertankers for carrying petroleum are put into service.

Regular hovercraft service starts across the English Channel. *See also* 1959 TRAN.

The first supersonic airliner, the Soviet Tupolev TU-144, is demonstrated on December 31. *See also* 1947 TRAN.

Aerotechnik Entwicklung und Apparatebau of Germany builds the WGM2 one-person, cheap, easy-to-fly helicopter. With its open seat, flying it is rather like riding a bicycle. *See also* 1939 TRAN.

René Thom

[b. Monbéliard, France, September 2, 1923, d. Bures-sure-Yvette, France, October 25, 2002]

Thom won the Fields Medal, mathematics' equivalent to the Nobel Prize, in 1958 for advances in geometry, but his true career was just beginning. After defining mathematically for the first time what it means for a statement to be true in general (not necessarily proved to be always true, however), he and his followers analyzed the ways that a general truth could fail, which came to be called catastrophe theory. The study of such failures, called catastrophes or singularities, has become an essential part of modern mathematics, physics, and mathematical biology, and is one of the elements of the better-known chaos theory.

1969

★ Astronomy

American astronauts land on the Moon. *See also* 1969 TRAN.

Thomas Gold and Franco Pacini [b. Florence, Italy, 1939] explain pulsars as rapidly rotating neutron stars that produce beams of synchrotron radiation; as these beams intersect Earth, they are detected as rapid on-and-off radio signals. *See also* 1967 AST.

In January William Cocke, Donald Taylor, and Michael Disney are the first to identify a visible star associated with a pulsar, the pulsar in the Crab Nebula. Previously, pulsars were known from radio signals only. *See also* 1968 AST; 1977 AST.

◆ Biology

Jonathan Beckwith and coworkers succeed in isolating a single gene; it is a bacterial gene for a step in the metabolism of sugar.

Brooklyn College professor Robert Whittaker [b. 1920, d. 1980] proposes a fifth kingdom of organisms, Fungi, for all fungi. The previously identified kingdoms are monerans (bacteria and blue-green algae), protists (more complex single-celled organisms), plants, and animals.

R. Bruce Merrifield [b. Fort Worth, Texas, July 15, 1921] makes the first synthetic enzyme, a copy of ribonuclease. *See also* 1946 CHEM; 1984 CHEM.

The Murchison meteorite is observed to fall near the small town of Murchison, Victoria, Australia, on September 18. Fragments are collected by local residents. Since the fragments appear to contain organic mat-

ter, they are analyzed by the same laboratory that has been set up to study Moon rocks for signs of life. Amino acids, the building blocks of proteins, are found, the first ever observed from any extraterrestrial origin. *See also* 1959 AST.

Max Delbrück, Alfred Hershey, and Salvador E. Luria of the United States win the Nobel Prize for physiology or medicine for their discoveries in the workings and reproduction of viruses. *See also* 1946 BIO; 1945 BIO.

◊ Chemistry

Derek Barton of England and Odd Hassel of Norway win the Nobel Prize in chemistry for the determination of the three-dimensional shape of organic compounds. *See also* 1949 CHEM; 1943 CHEM.

◆ Communication

ARPANET, the U.S. Defense Department precursor of the Internet, is born. *See also* 1966 COMM.

Jazz pianist Paul Bley is the first person to perform with a music synthesizer in front of a live audience. Previous uses of synthesizers were only on records. *See also* 1960 COMM.

The IBM Corporation improves the magnetic automatic typewriter by substituting a card instead of a tape. The new device is known as the Mag Card Selectric. *See also* 1964 COMM; 1972 COMM.

Don Wetzel, who works for a Texas manufacturer of automated baggage systems, develops the Automated Teller Machine (ATM). The first model is installed at a branch of Chemical Bank on Long Island in New York. The first

models are not linked with other machines as later ones will be. *See also* 1977 COMM.

■ Computers

The RS-232-C standard for data exchange between computers and peripherals, such as a modem, is introduced for the serial transmission of data. *See also* 1964 COMM; 1972 COMM.

“Bubble memory” devices are created for use in computers. Unlike conventional memory devices, bubble memory continues to remember even when the computer is turned off.

⊕ Earth science

John H. Ostrom of Yale University [b. 1928] resurrects Thomas Henry Huxley’s theory that birds evolved from dinosaurs.

A fossil of *Lystrosaurus*, a 240,000,000-year-old therapsid (mammal-like reptile) is found at Coalsack Bluff in Antarctic, indicating that Antarctica was once connected by land to Africa, where *Lystrosaurus* was common hundreds of millions of years ago. *See also* 1967 EAR.

▷ Ecology & the environment

The U.S. Congress creates the Environmental Protection Agency (EPA).

An offshore drilling blowout at Santa Barbara, California, spills 11,000,000 gallons of oil, arousing public anger against oil pollution. *See also* 1967 TRAN.

▼ Energy

A solar furnace is built at Odeillo in the French Pyrenees. It uses a paraboloid mirror to

concentrate sunlight to produces an output of 1000 watts of electricity. The furnace is also used to produce extremely high temperatures for various scientific experiments, also. *See also* 1949 ENER.

◊ Materials

Soviet cosmonauts aboard the orbiting *Soyuz 6* perform the first welding experiments in space.

Σ Mathematics

The new U.S. military draft lottery gets off to a bad start when workers use a selection procedure that is not random. Men born in the later months of the year are much more likely to be drafted than those born in the early months.

♥ Medicine & health

British physiologist Robert Jeffrey Edwards and surgeon Patrick Steptoe [b. Oxford, England, June 9, 1913, d. Canterbury, England, March 21, 1988] perform the first successful fertilization *in vitro* of a human ovum; the first “test-tube baby” resulting from this technique is born in England in 1978. *See also* 1978 MED.

In Texas, Denton Cooley [b. Houston, Texas, August 22, 1920] and Domingo Liotta [b. Entre Ríos, Argentina, 1924] replace the diseased heart of Haskell Karp with the first artificial heart to be used in a human being; Karp lives for nearly three days. *See also* 1968 MED; 1982 MED.

Elisabeth Kübler-Ross [b. Zurich, Switzerland, July 8, 1926], in *On Death and Dying*, introduces five stages of dying that people go through in progression: denial, anger, bargaining, depression, acceptance.

* Physics

Roger Penrose [b. England, August 8, 1931] shows that singularities predicted by Einstein's general relativity can be "clothed" (that is, restricted in their influence) by black holes. "Naked" singularities would destroy the universe, and since it has not been destroyed, do not exist.

Murray Gell-Mann of the United States wins the Nobel Prize in physics for his classification of elementary particles. *See also* 1961 PHY.

I Tools

An atomic clock built by the U.S. Naval Research Laboratory based on the natural vibration of ammonia molecules achieves a precision of 1 second in 1,700,000 years. *See also* 1949 TOOL.

→ Transportation

On March 3 the United States launches space vehicle *Apollo 9* with astronauts David Scott, James McDivitt, and Russell Schweickart [b. Neptune, New Jersey, October 25, 1935] aboard. It is the first flight of all lunar hardware, including a lunar module (LM). It successfully lands on March 13. On May 18 *Apollo 10* carries astronauts Thomas Stafford, Eugene Cernan, and John Young into space and into lunar orbit. The purpose of this flight is to evaluate LM performance in a lunar environment. The mission includes a descent of the LM piloted by Stafford and Cernan to within 14,326 m (47,000 ft) of the Moon's surface. The LM successfully rejoins the command module in orbit and all three astronauts return to Earth on May 26.

American astronaut Neil

Armstrong on July 20 becomes the first human being to stand on the Moon, part of the *Apollo 11* mission launched on July 16. Crewmate Buzz Aldrin is right behind him, while the other member of the *Apollo 11* crew, Michael Collins, orbits the Moon. Armstrong and Aldrin achieve the mission goals of limited inspection, photography, evaluation, and sampling of lunar soil. *Apollo 11* returns to Earth July 24. A second lunar landing mission, *Apollo 12*, begins with a launch on November 14 and lands on the Moon on November 19. Charles Conrad, Richard Gordon, and Alan L. Bean [b. Wheeler, Texas, March 15, 1932] travel to the Moon. Conrad and Bean spend over 15 hours exploring the surface of the Moon. The crew returns to Earth on November 24.

The Soviet *Soyuz 4* mission with cosmonaut Vladimir Shatov aboard is launched on January 14; it docks with *Soyuz 5* in first linkup of two space vehicles that both carry people; it completes 48 orbits. *Soyuz 5* is launched with Boris V. Volynov, Alexei S. Yeliseyev,

and Yevgeni V. Khrunov as crew; they all temporarily leave the spacecraft for space-walks and then are transferred to *Soyuz 4* in rescue rehearsal. The Soviet *Soyuz 6* mission starts off on October 11 with Georgi S. Shonin and Valery N. Kubasov in its crew; this is the first triple launch, as *Soyuz 7* launches October 12 (with Anatoly V. Filipchenko, Vladislav N. Volkov, and Viksot V. Gorbatko as crew) and *Soyuz 8* (with cosmonauts Vladimir A. Shatalov and Aleksei S. Yeliseyev) on October 13. Experiments in navigation and photography are conducted with *Soyuz 6*, 7, and 8.

On March 2 the Concorde supersonic passenger jet airplane, developed jointly by France and Britain, has its first test flight. *See also* 1968 TRAN.

1970

▲ Archaeology

Denise Schmandt-Besserat realizes for the first time that the tokens she has been studying as a part of her research on the uses of clay are actually a part of a system of account-

ing that existed in the Near East from about 8000 BCE to about 3000 BCE; it will not be until 1974, however, that her first paper exploring this idea is published. *See also* 1959 ARCH; 1972 ARCH.

★ Astronomy

Vera Cooper Rubin [b. Philadelphia, Pennsylvania, July 23, 1928] and W. Kent Ford report that their measurements of the Andromeda Galaxy show that its outer regions rotate too slowly to be explained by the amount of mass observable in the galaxy. There must be some mass present that is not observable. This begins the search for "missing mass" in the universe. *See also* 1933 AST; 1985 AST.

On January 3 a fireball as bright as the full Moon has its orbit determined by the Prairie Fireball Network. The 10-kg (22-lb) main body is found near Lost City, Oklahoma, on January 10 and three other pieces that total another 7 kg (15 lb) are later located. This is the second fireball to be tracked from the atmosphere and then recovered. *See also* 1959 AST; 1977 AST.



HUMANS WALK ON THE MOON Buzz Aldrin and Neil Armstrong became the first humans to walk on the surface of the Moon. Here Aldrin stands in his spacesuit beside one of the experiments conducted on the *Apollo 11* mission (studying composition of the solar wind). In the background is the Lunar Module *Eagle* that transported Armstrong and Aldrin from the orbiting Command Module *Columbia* to the surface and then back to *Columbia*.

The 100-m (328-ft) radio “dish” at Effelsberg (Germany) is completed. It will be the largest fully steerable dish for the next 30 years. *See also* 2000 astr.

Antoine Labeyrie [b. 1943] invents the technique of speckle interferometry. This technique combines the distorted speckles of light from different paths in a telescope, which helps eliminate the blurring effects of the atmosphere. *See also* 1960 AST.

On August 17 the Soviet Union launches *Venera 7*, the first Venus probe to return signals from the surface of the planet.

On September 12 the Soviets launch *Luna 16*, the first space probe to land on the Moon without humans aboard. It scoops up samples and returns them to Earth. On November 10 the Soviets launch *Luna 17*, which carries a roving vehicle to the Moon’s surface; the vehicle roams for two weeks at a time (during daylight), then “sleeps” during darkness; *Luna 17* returns photos and other data to Earth.

Uhuru, the first X-ray satellite telescope, is launched from Kenya by the United States on December 12. Among its accomplishments is the first identification of a possible black hole (*Cygnus X-1*, later confirmed by other X-ray and visual observations), as well as discovery of pulsed X-ray sources such as *Cen X-3* and *Her X-1*, produced by binary systems in which one member is a neutron star. *See also* 1962 AST; 1978 AST.

Biology

Howard Martin Temin [b. Philadelphia, Pennsylvania, December 10, 1934, d. Madison, Wisconsin, February 9,

1994] and David Baltimore [b. New York City, March 7, 1938] discover reverse transcriptase in viruses; this enzyme causes RNA to be transcribed onto DNA, a process that is another key step in the development of genetic engineering. *See also* 1975 BIO.

Daniel Nathans [b. Wilmington, Delaware, October 30, 1928, d. Baltimore, Maryland, November 16, 1999] and Hamilton Othanel Smith [b. New York City, August 23, 1931] discover the first type II restriction enzyme, an enzyme that always breaks a DNA molecule at a specific junction of bases. These type II restriction enzymes later become one of the basic tools of genetic engineering. *See also* 1968 BIO; 1978 BIO.

A team of scientists at the University of Wisconsin led by Har Gobind Khorana announce the first complete synthesis of a gene, aniline-transfer RNA. Previous workers had used a natural gene as a template, but in this case the gene was assembled directly from its component chemicals. *See also* 1967 BIO.

Retroviruses, which make DNA using an RNA template, are discovered. *See also* 1972 BIO.

Julius Axelrod, Ulf von Euler, and Sir Bernard Katz win the Nobel Prize for physiology or medicine for discoveries in the chemical transmission of nerve impulses. *See also* 1961 MED; 1946 BIO; 1952 BIO.

Chemistry

Argentine biochemist Luis Federico Leloir wins the Nobel Prize in chemistry for his discovery of sugar nucleotides and

their biosynthesis of carbohydrates. *See also* 1947 CHEM.

Communication

Kenneth Thomson and Dennis Ritchie at Bell Labs develop Unix, an operating system for both small- and medium-sized computers. It becomes the standard for multitasking and multi-user systems. *See also* 1972 COMM.

Niklaus Wirth develops Pascal (named for Blaise Pascal, who invented the first calculator), a popular language used on personal computers. *See also* 1965 COMM; 1972 COMM.

The daisy wheel printer, an impact printer using a metal wheel with spokes that are tipped with letters to print with an inked ribbon, is introduced for use with computers. *See also* 1961 COMM; 1971 COMM.

Xerox establishes at Stanford the Palo Alto Research Center (PARC), a center for non-commercial computer research; work at PARC leads to the development of Ethernet and the concept of a graphical user interface based on small images called icons. *See also* 1973 COMM.

The floppy disk is introduced for storing data used by computers. *See also* 1956 COMM; 1978 COMM.

Computers

Edward H. Shortliffe at Stanford develops MYCIN, a medical expert system based on 500 if-then rules. *See also* 1968 COMM; 1986 COMM.

Terry Winograd develops SHRDLU, a dialogue system that allows a computer to converse about a table-top world containing building

blocks. It permits simple manipulation of blocks and the description by the computer of results of certain manipulations. *See also* 1968 COMM; 1986 COMM.

On June 30 IBM announces the System/370 mainframe computer, their first mainframe to use fully integrated microchips for data storage and computation.

Control Data Corporation (CDC) introduces the STAR 100 computer, which has a vectorial architecture — a non-von Neumann design in which information is processed as vectors instead of as numbers; this allows a faster speed when a problem can be expressed in vector form. *See also* 1971 COMP.

Earth science

The U.S. Defense Department starts developing the Global Positioning System (GPS) for the military, consisting of 21 satellites. By receiving the radio signals from three or more of them, a person will be able to determine any position on Earth within 23 m (75 ft).

Ecology & the environment

The U.S. environmental movement makes itself felt on April 22 when about 20,000,000 Americans participate in ceremonies such as teach-ins and rallies to celebrate the first Earth Day. *See also* 1968 ECOL; 1972 ECOL.

Electronics

Charles A. Burrus [b. Shelby, North Carolina, July 16, 1927] develops an improved form of the light-emitting diode (LED). *See also* 1962 ELEC; 1990 ELEC.

RCA introduces the metal-oxide semiconductor (MOS) technology for the fabrication of integrated circuits, making them cheaper to produce and allowing greater miniaturization. *See also* 1958 ELEC; 1976 ELEC.

Intel introduces a memory chip that can store 1024 bits of data, replacing the voluminous ferrite core memories for computers; the chip brings in \$9,000,000 in revenue to Intel in its first year of sales. *See also* 1968 ELEC.

❖ Materials

Researchers at Corning create highly transparent fibers that will become the basis of fiber optics, used for high-capacity communication. *See also* 1966 COMM.

Σ Mathematics

Stephen A. Cook shows that a problem in formal logic, called the satisfiability problem, is exactly as difficult as any problem in a large range of problems that can be solved by a kind of Turing machine. This opens the door to finding that very many problems once thought to be distinct are essentially the same problem. *See also* 1971 MATH.

Yuri V. Matiyasevich [b. Leningrad (St. Petersburg, Russia), March 2, 1947] demonstrates that Hilbert's tenth problem (from the famous list of 23 major unsolved problems in mathematics), finding a sure-fire method for determining whether or not a given Diophantine equation (a polynomial equation with integral coefficients for which the variable is a vector) has integral solutions, is unsolvable. *See also* 1900 MATH.

♥ Medicine & health

The U.S. Food and Drug Administration (FDA) approves lithium as a treatment for bipolar disorder. *See also* 1949 MED.

⌘ Physics

Yoichiro Nambu, Leonard Susskind, and Holger Nielsen independently suggest the possibility of a theory of interacting one-dimensional objects (relativistic vibrating strings) to explain particle physics. *See also* 1974 PHY.

Yuri Gofland and Evgeny P. Likhtman develop the first supersymmetric field theory in four dimensions. *See also* 1971 PHY.

Hannes Alfvén of Sweden and Louis Néel share the Nobel Prize in physics, Alfvén for work in plasma physics and Néel for work in antiferromagnetism. *See also* 1950 EAR; 1936 PHY.

I Tools

Carbon-dioxide lasers are introduced for industrial cutting and welding. *See also* 1963 TOOL; 1976 TOOL.

Jacques Pankove, H. Paul Maruska, and others working at RCA in the United States develop the first blue-light laser from a semiconductor using gallium nitride, but it is not a practical device. *See also* 1962 TOOL.

✈ Transportation

On April 11 the United States launches *Apollo 13*. The mission starts off with astronauts James Lovell, Fred W. Haise, Jr. [b. Biloxi, Mississippi, November 14, 1933] and John L. Swigert, Jr. as crew. The attempt at a third lunar landing is aborted owing to loss of

pressure in liquid oxygen in the service module and fuel cell failure, but the ship and crew return safely to Earth after traveling around the Moon.

Soviet cosmonauts Andrian Nikolayev and Vitaly I. Sevastianov are launched on June 2 for the *Soyuz 9* mission, the longest spaceflight to date, lasting 17 days 6 hours.

Ohsumi is the first satellite launched by Japan, on February 11.

On April 24 China launches its first satellite, *Mao I*; it broadcasts the song "The East Is Red" once a minute from orbit, pausing at the end to send other signals.

The first of the "jumbo jets," the Boeing 747, with a two-story cabin capable of carrying more than 400 passengers, goes into service across the Atlantic on January 21. *See also* 1949 TRAN.

1971

★ Astronomy

On May 30 the United States launches *Mariner 9*, which becomes the first human-built object to orbit another planet when it enters orbit around Mars on November 13. Initial results are few because Mars is covered by a huge dust storm, but *Mariner 9* eventually returns 7329 pictures, many of them of great clarity.

Irwin I. Shapiro discovers superluminal sources by using very-long-baseline interferometry. These are components of quasars that appear to move away from each other at speeds greater than the speed of light. *See also* 1957 AST.

Two more American space missions visit the Moon and return with lunar material. *See also* 1971 TRAN.

On May 19 the Soviet space probe *Mars 2* is launched. It goes into orbit around Mars on November 27, just 14 days after the U.S. probe *Mariner 9*. It has a lander that crashes into Mars's surface. On May 28 the Soviet Union launches *Mars 3*, which goes into orbit about Mars on December 2. It releases a capsule that becomes the first space probe to soft-land on Mars, although it ceases functioning after 20 seconds.

凡本网

Floyd E. Bloom [b. Minneapolis, Minnesota, 1936] and coworkers at the National Institute of Mental Health show that cyclic AMP is involved in signaling between neurons. *See also* 1956 BIO.

Yoshio Masui and L. Dennis Smith independently discover that a substance, christened maturation promoting factor (MPF), controls the time that mitosis or meiosis begins in frog eggs. Later workers show that MPF has functions in all mitotic cells.

Earl Sutherland of the United States wins the Nobel Prize for physiology or medicine for the discovery of cyclic AMP. *See also* 1956 BIO.

□ Chemistry

Robert Woodward synthesizes vitamin B₁₂. *See also* 1956 CHEM.

German-Canadian physicist Gerhard Herzberg wins the Nobel Prize in chemistry for his study of the geometry of molecules in gases. *See also* 1959 CHEM.

Exploring the planets

If you are old enough, and especially if you were interested in astronomy or science fiction in your youth, you once knew a lot about the solar system that was simply not true. Among these fictions are that Mercury always keeps the same face to the Sun, that Venus is covered with water, that there are canals on Mars, that Jupiter has nine moons, and that Saturn is the only planet with rings. Today people know that these ideas are wrong because we have been there — not in person but with various sensors.

For example, in 1965 radar, developed during World War II, was used to find the correct rotation of both Mercury and Venus. Not only did we learn that Mercury doesn't keep the same face to the Sun, but we also learned that Venus rotates backwards, with the Sun rising very slowly in the west and setting in the east, 247 of our days later.

A technological product of the war, the giant liquid-fueled rocket, was the main key to our new knowledge of the solar system. These rockets provided the power to send probes to virtually all the planets.

Venus was the first planet to be visited by probes. Because of the gravitational pull of the Sun, Venus and Mercury are "downhill" from Earth, while the other planets are "uphill." The first U.S. space probe aimed toward Venus, *Mariner I*, landed at the bottom of the Atlantic Ocean because of a programming error, but *Mariner II* made it to the Venus neighborhood on December 14, 1962. Sensitive radio detectors revealed that Venus was far too hot to have liquid water. In 1966 the Soviet Union actually struck Venus with a probe, but it failed to transmit any information. The next year the Soviets had a somewhat more successful landing, while the U.S. *Mariner V* flew past at about the same time. Both revealed that in addition to the heat, the atmosphere was very dense. In 1975 the U.S.S.R. *Venera 9* and *10* soft-landed and returned pictures, showing Venus to be a bleak place. In 1978 the United States returned to Venus exploration with a Venus orbiter and another spacecraft that launched probes into the atmosphere. In 1982 the Soviets landed two more spacecraft that returned pictures and other data. As a result of this series of explorations, it has been possible to compile maps of Venus and to determine a great deal about its atmosphere.

Mars has long been of special interest because of the possibility that it may harbor living organisms, which still has not been completely ruled out, although most evidence so far is negative. In the early 1960s, both the Soviet Union and the United States launched several failed missions to Mars. Finally, on July 14, 1965, the U.S. space probe *Mariner IV* passed close to Mars. In 1969 two more U.S. space probes made flybys of the red planet. But 1971 was a banner year that saw two Soviet and one U.S. spacecraft in orbit about Mars, transmitting data, including television pictures, back to Earth. At first it seemed that nothing would be learned

from orbiting Mars, since it was impossible to see much through the atmosphere. Later it was found that the orbiting probes had arrived during a giant dust storm. When the dust died down, after several months, it became possible to map sections of Mars and to begin to study its geology — or "marsology," since geology is the study of Earth's rocks, landforms, and so forth.

In 1971 the Soviets made two attempts to land on Mars, but the space probes crashed onto the planet, although the second broadcast data for a few seconds. In 1976, however, two U.S. spacecraft *Viking 1* and *2* landed on Mars. They did not find life, but *Viking 1* broadcast data about its vicinity until May 1983, long after its expected "life."

On March 2, 1971, the United States launched *Pioneer 10* on a mission designed to go beyond Mars. It was one of the most successful missions ever. In 1973 *Pioneer 10* flew by Jupiter, providing data on its magnetic field and its moons. Then it just kept going. On June 13, 1983, *Pioneer 10* passed beyond the orbit of the then farthest planet, Neptune. (Pluto, which is usually the farthest planet from the Sun, has such an irregular orbit that for about 25 years out of its 248-year trip around the Sun it is inside the orbit of Neptune.) *Pioneer 10* kept going and continued broadcasting information until January 23, 2003, when it was 7,600,000,000 miles from Earth. It now coasts through space as a ghost probe.

In 1974 the U.S. *Mariner 10*, after a glance at Venus, became the first space probe to reach the vicinity of Mercury. It was also the second and third, as it went into orbit about the Sun, and flew past Mercury more than once, exploring the planet from space each time.

Another Pioneer, *Pioneer 11*, was the first to reach Saturn, in 1979, revealing evidence of more moons than had previously been known.

But the most successful trip of all was that of *Voyager 2*. Together with *Voyager 1*, *Voyager 2* flew by Jupiter in 1979 and by Saturn in 1980 and 1981, but then they parted company. While *Voyager 1* headed for empty space, *Voyager 2* continued on to Uranus, which it reached in 1986 and to Neptune, which it passed by in 1989. Like the Pioneer mission, the Voyagers located additional moons. In passing Saturn, they provided spectacular close-up views of the famous rings. *Voyager 2* also produced close-ups of the rings of Uranus and Neptune, which had been discovered from Earth by more conventional means.

In 1989 *Galileo* began a successful study of Jupiter, passing close to Venus, Earth, and two asteroids along the way. Further exploration of Mars, including an orbiters and landers with robot rovers is continuing. *Cassini-Huygens*, launched in 1997, flew past Venus, Earth, and Jupiter on its way to rendezvous with Saturn and its main moon Titan in 2004. Pluto remains the only planet yet to be visited by a space probe, although the New Horizons Pluto-Kuiper mission is scheduled for launch in 2006.

Communication

Starting now and continuing into 1972, Ray Tomlinson, a computer scientist at an engineering firm in Cambridge, Massachusetts, writes the first e-mail program — that is, the first program to send mail from one computer to another — introducing the @ sign to separate the name of the addressee from the name of the computer locations. *See also* 1972 COMM.

Direct telephone dialing, as opposed to operator-assisted calls, begins between parts of the United States and Europe on a regular basis.

Centron in the United States introduces the dot matrix printer, which uses an array of dots that are individually raised to press ink from a ribbon onto paper, one letter at a time. Dot matrix printers for computers become widely applied for both text and graphics. *See also* 1970 COMM; 1976 COMM.

Raj Reddy [b. Katoor, India, June 13, 1937] at Carnegie Mellon University develops Hearsay, a software program for speech recognition by computer. The project, called SUR (Speech Understanding Research), is funded by DARPA, the research arm of the U.S. armed services. *See also* 1968 COMM; 1976 COMM.

Sony introduces the videocassette for home recording of television programs. *See also* 1965 COMM.

Dennis Gabor of England wins the Nobel Prize in physics for his invention of holography. *See also* 1948 COMM.

Computers

John Cocke [b. Charlotte, North Carolina, May 30, 1925, d. Valhalla, New York, July 16, 2002] and coworkers at IBM recognize that a computer can function with just the most commonly used instructions, omitting the less commonly used from the computer altogether. This line of work produces the RISC (Reduced Instruction Set Computing) processor by the 1980s. *See also* 1975 COMP.

Patrick Eugene Haggerty [b. Harvey, North Dakota, March 17, 1914, d. Dallas, Texas, October 1, 1980] of Texas Instruments introduces the first pocket calculator, the Pocketronic. It can add, subtract, multiply, and divide only; it weighs more than a kilogram (about 2.5 pounds) and it costs around \$150. *See also* 1889 COMP; 1974 COMP.

Earth science

In Texas, Douglas Lawson [b. 1947] discovers fossils of the largest flying animal found to that date, a pterosaur he names *Quetzalcoatlus northropi*.

Ecology & the environment

The U.S. government passes the Lead Paint Poisoning Prevention Act, which requires that interior paint applied before 1955 must be stripped from buildings; the act is never fully implemented, however. *See also* 1955 ECOL; 1980 ECOL.

Electronics

The first microprocessor (an integrated circuit used as a central processing unit), commonly known now as the

"chip," is introduced by Intel in the United States. Marcian "Ted" Hoff [b. Rochester, New York, October 28, 1937], Stan Mazor, and Federico Fagin develop the Intel 4004 microprocessor. It contains 2300 transistors on a 7 mm by 7 mm silicon chip and can process 4 bits at a cycle rate of 60,000 per second. *See also* 1968 ELEC; 1972 ELEC.

Gary Boone and Michael Cochran develop the TMS 1000 microprocessor; it receives the first patent for such a device. The TMS 1000 combines input circuits, memory, a central processor, and output circuits all on one chip; the chip is widely applied in pocket calculators. *See also* 1972 ELEC.

Energy

In the Soviet Union the first semi-industrial scale magnetohydrodynamic (MHD) power generator is announced in April. Such a generator produces electricity by passing a conducting fluid through a magnetic field. The Soviet generator is designed to produce 25 megawatts and to use natural gas. A German MHD generator also goes into operation in April, but it produces only 1 megawatt.

In Canada, the first nuclear power reactor that is cooled by ordinary water goes into service. *See also* 1963 ENER.

Materials

James Ferguson and coworkers at the International Liquid Xtal Company develop the twisted nematic liquid crystal that will become the basis of liquid-crystal electronic displays. The twisted liquid crystal is first used as a display for a watch. *See also* 1958 MATR.

Mathematics

Stephen A. Cook defines the class of nondeterministic polynomial complete problems (called "NP complete"). Their solutions are difficult to find, but easy to verify. *See also* 1970 MATH.

Medicine & health

Raymond V. Damadian [b. Forest Hills, New York, March 16, 1936] applies for a patent on using magnetic resonance imaging (MRI, also known as NMR) to detect tumors. *See also* 1937 PHY; 1977 MED.

Choh Hao Li synthesizes human growth hormone.

Chemists at the Research Triangle Institute in North Carolina isolate the active ingredient of a powerful anticancer drug made from the bark of Pacific yew trees. Anticancer activity of extracts from the bark had been known since the 1960s. They name the active ingredient taxol. *See also* 1992 MED.

In the United Kingdom, the diamond-bladed scalpel is introduced.

The U.S. Food and Drug Administration asks doctors to stop prescribing diethylstilbestrol (DES) to control morning sickness in expectant mothers because of evidence that the drug predisposes their daughters to cancers of the reproductive tract. *See also* 1961 MED.

John R. Vane [b. Tardebigg, Worcestershire, England, March 29, 1927] discovers that aspirin works in part by inhibiting the production of body chemicals called prostaglandins. *See also* 1982 BIO.

In the United States it is

shown that electric currents can speed the healing of fractures. *See also* 1987 MED.

In the United Kingdom, the first completely sterile hospital units are introduced to protect patients at special risk from infection. *See also* 1865 MED.

* Physics

Pierre Ramond, André Neveu, and John Schwarz develop a string theory that includes

both fermions and bosons. Jean-Loup Gervais and Bunji Sakita [b. 1930, d. August 31, 2002] show that this theory obeys what turns out to be a supersymmetry algebra in two dimensions. Soviet physicists Yuri Golfand and E. Likhtman discover supersymmetry in four space-time dimensions. *See also* 1970 PHY.

Ilya Prigogine [b. Moscow, January 25, 1917, d. Brussels, May 28, 2003] develops the

laws concerning thermodynamics before equilibrium is reached. He concludes that the distribution law of fluctuations depends on their scale. Small fluctuations behave as in previous theories, but large ones require an entirely different mathematical treatment. *See also* 1977 CHEM.

Nevill Francis Mott [b. Leeds, England, September 30, 1905, d. Milton Keynes, England, August 12, 1996] writes

Metal-Insulator Transitions, which treats his fundamental work in the 1960s with amorphous semiconductors. *See also* 1977 PHY.

Gerardus t'Hooft [b. Den Helder, Netherlands, July 5, 1946] proves the renormalizability of massless Yang-Mills fields and of massive Yang-Mills fields with spontaneous broken symmetry. *See also* 1954 PHY.

Scanning the body

Visualizing the interior of the body with X rays and radioactive tracers revolutionized diagnosis, but both techniques were far from perfect. Images were often difficult to see, interpretation was complicated, and both technologies employed damaging radiation.

Although the comic book hero Superman could focus his X-ray vision on details, medical X rays originally involved no such discrimination. Radiation passed through the body and collected on a flat piece of film or fluoroscope screen. Images from different planes within the body were merged into a single plane. As early as 1917, however, mathematicians had shown that images from several different angles could be combined to give three-dimensional views. An early effort to accomplish something like this was made by Dutch radiologist Ziedes de Planter. He used a moving X-ray source to obtain a single "slice" of the target. The mathematical method for building an image uses a large number of such slices to reconstruct the target object, a procedure termed tomography ("slice writing"). An immense amount of calculation is needed, however, to assemble a three-dimensional image from slices.

After World War II, the invention of powerful computers made mathematical tomography feasible. Several groups of physicians and scientists in England, South Africa, and the United States developed the method separately. Today this three-dimensional method, originally called computer-assisted tomography (CAT), but now known as computed tomography (CT), has become a common diagnostic tool.

A different tomographic technique was also developed, one that combines some ideas of radioactive tracers with something like X rays. Gamma rays, like X rays, are high-energy electromagnetic waves, but gamma rays are even more energetic than X

rays. In a technique called positron emission tomography (PET), the radioactive tracer emits positrons (antielectrons). When these encounter electrons, the two particles annihilate each other and produce a gamma-ray photon. The gamma-ray camera, developed in the 1960s, captures the images formed as the gamma rays leave the body. These images can also be collected in slices and reconstructed to form an image called a PET scan. The PET scan has been especially useful in monitoring brain activity by using tracers that flow to where neurons are firing.

The CT scan produces good images, but still uses damaging X rays, and the PET scan produces small amounts of even higher energy radiation. Another approach solves that problem and achieves more as well. Chemists found a way to use magnetic fields to make specified atoms or parts of molecules produce characteristic radio waves on demand. Powerful electromagnets cause the nuclei of atoms to line up, somewhat the way that iron filings can be aligned by an ordinary horseshoe magnet. When the field is removed, the nuclei return to their normal disarray, in the process emitting radio waves at frequencies that vary depending on the particular nucleus and its state in a molecule. Chemists call this method nuclear magnetic resonance (NMR). Radio waves are also electromagnetic, but much lower in energy than X rays or gamma rays. Weak radio waves and strong magnetic fields, used to induce the radio waves, are not thought to be harmful.

In the early 1970s several inventors, notably Raymond Damadian, created machinery that could use this effect on whole human bodies. Medical doctors renamed nuclear magnetic resonance, however, out of fear that patients would think NMR had something to do with nuclear fission or fusion. The medical imaging, now known as magnetic resonance imaging (MRI), reveals soft tissue that would not be otherwise observable. Actually, an MRI scan provides the safest way to look inside the body.

✈ Transportation

U.S. astronauts Alan Shepard, Stuart A. Roosa, and Edgar D. Mitchell begin the *Apollo 14* mission on January 31; they complete the third lunar landing and return 98 pounds of lunar material. *Apollo 15* is launched on July 26 with David Scott, Alfred M. Worden, and James B. Irwin in its crew; they complete the fourth lunar landing, carry a Lunar Roving Vehicle (LRV), return 173 pounds of material, and spend 18 hours 46 minutes in EVA.

Soviet cosmonauts Vladimir A. Shatalov, Alexei S. Yeliseyev, and Nikolai N. Volkov begin the *Soyuz 10* mission on April 23; the craft docks with *Salyut 1*, the first space station (launched April 19). Soviet cosmonauts Georgi Dobrovolsky, Viktor I. Patsayev, and Vladislav N. Volkov begin the *Soyuz 11* mission on June 6 and spend 23 days on the space station. All three cosmonauts are killed during reentry by a failure of pressurization.

1972

▲ Archaeology

Pierre Amiet is the first to connect clay envelopes filled with stones or fired clay objects (later called tokens) with the development of numeration. *See also* 1970 ARCH.

★ Astronomy

A Soviet spacecraft, *Venera 8*, soft-lands on Venus.

On March 2 the United States launches *Pioneer 10*, the first space probe to study Jupiter. On June 13, 1983, it is the first probe to leave the solar system.

U.S. astronauts make two more visits to the Moon and return

with lunar rocks for further analysis. *See also* 1972 TRAN.

❖ Biology

Paul Berg [b. New York City, June 30, 1926] inserts a human gene into the DNA of a bacterium, producing the first recombinant DNA molecule. *See also* 1970 BIO; 1973 BIO.

Stephen Jay Gould [b. New York City, September 10, 1941, d. New York, May 20, 2002] and American Niles Eldredge [b. 1943] publish their theory of punctuated equilibrium, stating that evolution often occurs in short bursts followed by long periods of equilibrium. *See also* 1894 BIO.

The California State Board of Education demands that the Biblical account of Creation receive equal attention in textbooks as Darwinian theory. *See also* 1859 BIO.

Andrew Wylie and coworkers coin the word *apoptosis* to describe programmed cell death, a built-in method of destroying cells after they are no longer useful in development. *See also* 2002 BIO.

Gerald M. Edelman and Rodney Robert Porter win the Nobel Prize in physiology or medicine for the determination of the chemical structure of antibodies. *See also* 1959 BIO; 1962 BIO.

▷ Chemistry

Americans Dudley R. Herschbach [b. San Jose, California, June 18, 1932] and Yuan T. Lee [b. Hsinchu, Taiwan, November 19, 1936] develop a “super-machine” for the crossed-beam molecular technique. It employs strong differential pumping, sophisticated mass spectroscopy using ion counting techniques adapted from

nuclear physics, and supersonic beam sources with the goal of interpreting reaction dynamics in terms of electron structure. *See also* 1986 CHEM.

Christian Anfinsen, Stanford Moore, and William H. Stein share the Nobel Prize for chemistry for their pioneering research in enzyme chemistry. *See also* 1959 CHEM.

⌚ Communication

Lexitron puts the first word processing system on the market. VYDEC Corporation introduces a word processing system that is immediately more successful. Wang Laboratories introduces a word processing system using the IBM Selectric typewriter as a printer. Text in the Wang system is stored on magnetic tape. *See also* 1964 COMM; 1978 COMM.

Threshold Technologies introduces the first speech-recognition system, the VIP 100. A computer can recognize a limited number of words when each word is pronounced separately. *See also* 1973 COMM.

Lawrence Roberts at the Advanced Research Projects Agency's Techniques Office writes the program RD, the first e-mail manager to include a filing system and a delete function. *See also* 1971 COMM.

Odyssey, the first home video game, developed by Ralph Baer [b. Germany, 1922] is introduced by Magnavox. Nolan Bushnell founds Atari and, with employee Al Acorn, invents Pong, a video game with a liquid crystal screen that is an immediate success, grossing \$11,000,000 in 1973. Players use electronic paddles to push a glowing dot back and forth. Atari will later start producing one of the earliest suc-

cessful personal computers. *See also* 1955 COMM; 1985 COMM.

Philips Corporation of the Netherlands introduces a disk-laser recording system they call Laservision. *See also* 1965 COMM; 1981 COMM.

Alan Kay introduces SMALLTALK, a computer language derived from Simula, especially adapted for graphics, including windows and icons. It is one of the first object-oriented languages. *See also* 1970 COMM; 1973 COMP.

Dennis Ritchie and Kenneth Thompson [b. New Orleans, 1943] at ITT Bell Labs develop “C,” a computer language running under the UNIX operating system. They use it to rewrite UNIX, replacing the original assembly language version of UNIX in 1977. Later versions, such as C++ by Bjarne Stroustrup [b. Aarhus, Denmark, 1950] become highly successful and will be widely used for writing software packages throughout the remainder of the century. *See also* 1971 COMM.

Alain Colmerauer in France develops PROLOG (PROgramming LOGic), a computer language developed for applications in artificial intelligence. *See also* 1959 COMM.

💻 Computers

Telenet Communications Corporation establishes a time-sharing computer network with terminals all over the world. TYMNET also establishes a communications network. *See also* 1969 COMP.

🏗 Construction

The World Trade Center in Manhattan, New York City, is completed in January. The two towers are 417 m (1368 ft) and 415 m (1362 ft) high, surpass-

ing the Empire State Building, also of Manhattan, in height. Both of its twin towers will be totally destroyed by a terrorist attack using two hijacked passenger airplanes on September 11, 2001. *See also* 1931 CONS; 2001 CONS.

Earth science

W. Jason Morgan of Princeton University extends the idea that the Hawaiian Islands were formed as the Pacific plate moved over a “hot spot,” where a plume of magma rises from the mantle, to include the Emperor Seamounts, a group of underwater volcanoes to the northwest of the Hawaiian Islands. *See also* 1963 EAR.

The United States launches *Landsat I*, the first Earth-resources satellite, on July 23. It uses a television camera and a multispectrum scanner, which captures images at various wavelengths of light, to broadcast to Earth images that can show such information as forest and mineral resources.

Ecology & the environment

The Club of Rome publishes its report, *The Limits to Growth*, also known as the Meadows Report, announcing that Earth will face environmental disasters if the trends of pollution and depletion of Earth’s resources continue. *See also* 1970 ECOL; 1973 ECOL.

In June the United Nations Conference on Human Environment meets in Stockholm, Sweden, to examine global environmental issues. *See also* 1970 ECOL.

In the United States, the use of DDT is restricted to protect the environment and wildlife, especially birds, whose eggshells are dangerously thinned, lowering the birds’ reproductive rate. Interstate sales of DDT are banned. *See also* 1939 FOOD.

The U.S. Congress passes a number of laws to protect the environment. It establishes the National Marine Sanctuary Program to create sanctuaries for ecological, scientific, and recreational purposes. The Ocean Dumping Act bans dumping of radiological, chemical, and biological warfare agents and high-level radioactive wastes. A revised Clean Air Act allocates \$95,000,000 to local, state, and national air pollution control efforts. *See also* 1963 ECOL.

Electronics

Intel develops the first eight-bit microprocessor chip, the 8008; it will be used in the MARK-8 “personal minicomputer” and other home computer kits in 1974. *See also* 1971 COMP; 1974 ELEC.

Energy

In Germany, an experimental power station uses coal that is converted to gas before being burned to produce electric power. *See also* 1985 ENER.

Mathematics

René Thom publishes *Stabilité structurelle et morphogenèse* (“structural stability and change”), which describes catastrophe theory. *See also* 1968 MATH.

Medicine & health

In the United Kingdom, the first experimental computerized axial tomography (CAT scan, later known as CT scan) imager for medical purposes, the head scanner EMI Mark 1 developed by Godfrey Hounsfield, is introduced at Atkinson Morley’s Hospital in Wimbledon. It takes 4.5 minutes to gather data followed by 20 minutes of computer time to construct an image. It detects a brain tumor in a living patient on October 4. *See also* 1967 MED.

Jean François Borel [b. Switzerland, 1933] discovers the immunosuppressant cyclosporine, which helps prevent rejection of organ transplants. It will be approved by the U.S. Food and Drug Administration (FDA) in 1983. *See also* 1957 MED.

David S. Janowsky and coworkers determine that bipolar disorder, commonly called manic depression, is caused by an imbalance between two types of neurotransmitters, the adrenergic and cholinergic.

Physics

In September Murray Gell-Mann presents the beginnings of quantum chromodynamics (QCD), the theory that links quarks and color forces, along with three different flavors of quarks — up and down, strange and charm, and bottom and top. *See also* 1965 PHY; 1979 PHY.

Boris Ya. Zel’dovich and coworkers use the phenomenon of stimulated Brillouin

scattering to create a beam of time-reversed light; such a beam can be transmitted through a distorting medium and be concentrated instead of distorted. *See also* 1964 PHY.

John Bardeen, Leon Cooper, and Bob Schrieffer of the United States win the Nobel Prize in physics for their theory of superconductivity without electrical resistance at a temperature of absolute zero. *See also* 1957 PHY.

Tools

The large accelerator at Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, begins operations at 200 GeV (giga electron volts, or 200,000,000,000 electron volts) and reaches 400 GeV later in the year. *See also* 1983 TOOL.

Transportation

U.S. astronauts John Young, Thomas Mattingly II, and Charles M. Duke are launched on April 16 to start the *Apollo 16* mission; they complete the fifth lunar landing, are the second to carry an LRV (Lunar Roving Vehicle), spend 18 hours 14 minutes in EVA, and return 213 pounds of material. Eugene Cernan, Ronald E. Evans, and Harrison Schmitt begin the *Apollo 17* mission on December 7. They complete the last manned lunar landing, the third with an LRV, have a total EVA time of 44 hours 8 minutes, and return 243 pounds of material. This is the last of the Apollo missions and the last attempt to send people to the Moon to date.



The Information Age: 1973 through 2003

During this period — the last quarter of the 20th century along with the beginning of the 21st — the focus in science, technology, and society became information itself as well as the means of conveying it. The word *information* encompasses but surpasses the concept of data. Its modern sense derives from the scientific work of Ralph V.L. Hartley in the 1920s and Norbert Wiener and Claude E. Shannon in the 1940s. But as often is the case with scientific concepts that cross over into public discourse (entropy and chaos are two recent examples), the idea of information has become somewhat of a catchall for much more than was intended by the scientists. Nevertheless, it is in this broader sense that the period since 1972 can be dubbed an Information Age.

Just as the introduction of machine tools in the 19th century led to the mechanization of society, progress in electronics and computers caused information to become one of the most important commodities during the last part of the 20th century. The combination of new developments in electronics, computer technology, information storage, communications, and display techniques thoroughly permeated all aspects of society. Progress in handling information also became a driving factor in the enormous expansion of technology and science during the last decades of the 20th century. The enormous advances in genetics can also be viewed as a revolution in information science — the identification of the information contained in the chromosomes of all living organisms in the form of the genetic code. The manipulation of this genetic

information became possible in 1973 with the first successes with a newly developed technology termed recombinant DNA. This has resulted in the creation of new medicines and genetically modified food crops.

About the same time biologists also began to learn that our immune system is also an information processing system, one that normally fights disease by transmitting information from cell to cell. Although it has yet to reveal all its mysteries, the immune system has become one of the major battlefields of medicine. Suppressing it was essential in transplanting organs or fighting autoimmune diseases; enhancing it selectively led to new vaccines or ways to fight cancer; and copying it was made possible monoclonal antibodies, one of the great successes in gaining information. Monoclonal antibodies are lines of very specific chemicals that react only with target substances (usually proteins), thus providing ways to identify the substances even in tiny amounts or to carry specific chemicals to the places where such substances exist.

A combination of new developments in data storage and retrieval, the Internet and other means of communication, display techniques, Earth satellite capabilities, and trends in society led to a technology revolution that began in the early 1970s and appears to be continuing today. The common thread binding the different pieces of this revolution is also information. The effect of a transition from goods and services to information can be felt in all enterprises. For example, the importance of traditional manufacturing (metalworking and construction) has sharply declined

relative to the newly emerged communications and information technology industries. Information and information processing are new “products” in which the trade has increased enormously in the last two decades.

Information and society

Information and information technology have also colored our view of the world, forming the new metaphor of our reality. The existence of metaphors for understanding the world is not a new phenomenon; during Galileo's and Newton's times, the world was viewed as clockwork and people as complicated mechanical machines. Today, many picture the human mind as a type of complicated computer. Parallel processing and neural networks are considered emulations of the way the nervous system operates, and many researchers in artificial intelligence (AI) believe that AI will ultimately lead to understanding of the human mind.

The acceptance of this new metaphor has widespread consequences. There is an inherent belief that even the most difficult problems will find a solution in information gathering and processing and in the power of software; examples are the use of expert systems in medicine and the way that modern warfare is based on weapons in which information and information processing are the most important aspects. Naturally, new terms have also appeared, such as “knowledge engineering.”

The value society attaches to information has increased not only because information has become a commodity, but because information technology

The Information Age: 1973 through 2003

and computers are considered the cutting edge of technological progress. Software and computers form the magic of the modern world. More than any other technology, the computer's possibilities seem unlimited. It is the new Eldorado for the inventive spirit. The mantle of the inventor entrepreneurs, such as Thomas Alva Edison, Alexander Graham Bell, and Henry Ford, is worn today by the information entrepreneurs — Steven Jobs of Apple and William Gates of Microsoft. But in the late 1990s, the optimism of information-based wealth faded as Internet industries — the “dot.coms” — became overvalued and precipitated an e-market stock crash.

The microchip — its inventors were awarded with the Nobel Prize in physics in 2000 — became the most ubiquitous manufactured object, comparable to the screw and bolt of the industrial era. The microchip profoundly changed science and technology. For example, powerful computers and fast data-acquisition technology allow the collection and processing of millions of signals produced in the large detectors used in particle accelerators whereby the search for very rare events can be automated. Information technology allowed the decipherment of the human genome — the sequence of the 3,100,000 “letters” contained in the DNA making up the 30,000 or so genes that are contained in the chromosomes of our cells. Computer modeling allows the creation of complex models ranging from the evolution of the universe to protein folding.

Another new idea employed is distributed computing. Four million PCs have been participating in a large search looking for extraterrestrial life, processing data received by the Arecibo radio telescope; while other large groups of PCs have combined to factor numbers to decipher the ways that proteins fold. In all these cases, home com-

puter users download and upload data for the projects and then use the extra computing capacity of their computers to work on solving these problems in the background all the time they are connected to the Internet.

Globalization

Communication worldwide became cheap and often instant with the advent of new phone systems and the Internet. This profoundly affected the way many aspects of society and of the economy operate. The way people work, for example, has changed. Many now use the superior communications capabilities of computers to work from home — they are sometimes called e-commuters. Information-based work can also be located in places where labor is cheapest. Dialing an information number (such as an 800 number) in the United States can, for example, put one in touch with an operator working in India who never has set foot in the United States. There is no way to recognize over the phone that you are talking with someone halfway around the world.

The trend in society for businesses to locate plants and other facilities in low-cost Third World countries was only part of what came to be called globalization. The technology for moving goods from place to place by container-ship or air made it cheaper to have cloth manufactured in China, clothing sewn in Malaysia or Thailand, fruits and vegetables grown in Chile for the North American winter market, and lamb chops or mussels shipped from New Zealand to Europe or the United States.

Another side of globalization was also about money. German and English publishers, for example, tended to own many subsidiaries around the world that once were independent and locally owned. Banks also became global in reach. An American traveling in England or even Russia could count on

using the same ATM card that worked at home. Yet one other aspect, and perhaps the most visible, consisted of the commercial penetration of the world by fast-food chains or other kinds of chains or franchised stores. The shopping areas of all large cities came to be dominated by the same few retail stores.

The scientific enterprise itself also became largely global. Many research papers are written by authors whose workplaces are separated by thousands of miles. Some research projects, especially in particle physics, are signed by hundreds of collaborators. The creation of the World Wide Web (WWW) at CERN, Europe's Particle Physics laboratory near Geneva in Switzerland, was a direct consequence of the globalization of research. The WWW was initially created to allow researchers to collaborate on large programs linked to the particle detectors in CERN's accelerators.

Furthermore, scientists at research institutions were writing more. Before the 1970s, top scientists usually wrote about two dozen articles in their lifetimes. As competition for jobs increased among the scientists, each person felt the need to write more research papers to make himself or herself more attractive to employers or to obtain tenure at universities. In many cases, the results of research were broken into small bits with each published separately in one of the thousands of scientific journals available by the 1980s. In a few cases, the same pressures resulted in fraud as scientists published sometimes spectacular results without taking the time and effort to gather or analyze data (experiments that could not be reproduced by their peers).

The post-industrial society

From time to time, the technological basis of society changes. The Agricultural Revolution made plows and sick-

les more important than bows and arrows. Engineers who could build aqueducts or dams created new agricultural land. During the Industrial Revolution of the 18th and 19th centuries, the technological base changed from agriculture and food production to manufacturing. Manufacture of goods became the main source of wealth, with mechanical engineers key contributors to the early phases, while scientists and inventors working with electricity became important at the end of the period.

Another major change began around the middle of the 20th century. In many economically advanced countries, services started to surpass manufacturing as the main source of income. This change gave rise to a new form of society, which in the early 1960s American sociologist Daniel Bell named the post-industrial society. In such a society wealth is generated by services instead of production of goods.

Bell identified five characteristics of a post-industrial society: 1) The majority of the labor force is engaged in the supply of services and not in manufacturing and food production. 2) Society requires an increased number of professionals and people with technical qualifications, especially in science and engineering. 3) Theoretical knowledge of science and technology becomes the basis for economic power and social policy, apparent in the development of high technology. 4) Technology and modeling become important in planning for the future. For example, technology assessment becomes important in studying the influence of new energy sources on the environment. 5) Intellectual technology takes over intellectual functions such as decision making.

The widespread proliferation of computers and information networks are examples of the new form of intellectual technology described by Bell. These developments decreased the

importance of the factory worker and the clerical worker, many of whose tasks were taken over by computers.

The advent of small, powerful computers in the 1970s began to make the United States into and beyond the society Bell had described. The number of face-to-face service transactions diminished, while more and more people were employed behind the scenes in serving each other. But at the level of the individual obtaining the actual service, the consumer was increasingly left to handle transactions alone. Banking with automatic teller machines (ATMs), pumping gas and charging it to a credit card at the pump, filling out the details of an online order for goods, and scanning prices for a grocery order that the customer bags himself, the service economy was becoming a self-service economy. Some restaurants even let the patrons cook their own orders. For the most part, the tasks of the bank teller, pump jockey, sales clerk, and checkout clerk were being taken over by a combination of the user and a computer, even when the computer was not visible.

Science questioned

The last few decades of the 20th century and the beginning of the 21st, the place of science in society also underwent a profound change. If in the past the scientific community could withdraw to its ivory tower, science was now much more in the public eye. Decisions on what kind of research would be performed were now much more controlled by society at large, and not only by the scientific community itself.

The perception of the aim of science also changed. In many areas the conquest of knowledge has become subsidiary to the benefits science can bring to society. Even astronomy, the science regarded with the lowest potential for benefiting society directly, now claims the necessity for protecting Earth

against the impact of asteroids. As a consequence, the public has been forced to make science-based choices.

While science has been progressing on all fronts, it also has been challenged in certain areas. Especially in the United States, religious groups insisted on teaching of “creation science,” an account of the origin of the world and humanity entirely based on the literal interpretation of the Bible, alongside evolution theory. For some a more acceptable form of creationism is “intelligent design,” a theory that accepts evolution to a certain degree, but argues that evolution is directed by a supernatural intelligence — a view most scientists reject. At the same time, embryonic stem cell research — the use of still undifferentiated cells taken from embryos — encountered opposition from religious groups. Although several successes were reported for cloning animals, human cloning remained out of bounds for most scientists. Animal clones were successful in only one out of dozens or hundreds of attempts; few scientists would risk attempts with humans at those low odds. Furthermore, some research in 2003 suggested that peculiarities in the human genome might completely prevent successful cloning.

In 1996 New York University physicist Alan Sokal published the now-famous article “Transgressing the Boundaries: Towards a Transformative Hermeneutics of Quantum Gravity” in the journal *Social Text*. The spoof, what became called the Sokal affair, exposed the fact that a large group of sociologists of science view many scientific ideas as “social constructs” — ideas on which a group of people (for example, physicists) are in agreement but have little bearing on reality. Apparently, absurd conclusions such as the Schrödinger’s cat and Einstein-Rosen-Podolsky paradoxes looked for a long time as good candidates for validating the “social construct” idea of science.

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However, experiments confirmed that the “counterintuitive” ideas of quantum mechanics represented physical reality. For example, in France, Alain Aspect showed in 1982 that photons can behave in a correlated fashion. They know about each other’s polarization, even when they can’t communicate.

Problems of the Information Age

Many fear that some aspects of a society based on information technology will form a threat rather than inspire social progress. For example, the use of large personal databases by government, insurance companies, and even marketing organizations can be viewed as infringement on personal privacy. Others believe that the superinflation of information forms a different threat. For example, excessive use of computers in teaching young children may impoverish the development of intellectual capabilities as a result of the specific and narrow fashion in which a computer stores and delivers information. For these critics the computer replaces “knowledge” with mere data: Ideas contain data, but data contain no ideas.

Criticism of basing society on information sometimes revolves around what some see as intrinsic limits to information processing. Star Wars — the U.S. Strategic Defense Initiative (SDI) — is often used as an example. In 1983 U.S. President Ronald Reagan announced the start of SDI, a satellite-based high-technology plan to provide an impenetrable barrier to enemy intercontinental ballistic missiles. Although several versions were designed and a few tests were conducted, it soon became apparent to most scientists that technical problems probably would keep the planned shield from being effective. In particular, difficulties in programming the complex software for the project seemed unsolv-

able. Reliable information for computers to use in launching nuclear weapons could not be produced fast enough. Furthermore, every experience with software in the past has shown that unanticipated problems almost always become apparent during actual operation. Since actual operation of the SDI system would entail a nuclear attack, there was no way to test the software programming. Although under President Bill Clinton, SDI was scaled back and quietly dropped, a limited form of the same idea was reinstated by U.S. leader George W. Bush. While political developments diminished the tension between East and West, and a “nuclear winter,” became less likely after the fall of the Berlin wall and collapse of the Soviet empire and state, scientists recognized new threats to the environment — global changes brought about by human activity. The depletion of the ozone layer, the global rise in temperature caused by an increased greenhouse effect, and general pollution levels in

the atmosphere and seas have pushed scientists to take action. Terrorism applied to biological, chemical, or “dirty” nuclear weapons also became a concern to the scientific community, and in 2003, in an unprecedented move, *Science* magazine decided not to publish details that might help the creation of biological weapons.

Major advances

ANTHROPOLOGY In recent years there has been a revolution in the early history of the ancestors of humans, which can be said to have started with the 1974 discoveries of the “Lucy” skeleton of *Australopithecus afarensis* in Ethiopia and *A. afarensis* footprints in Laetoli, Tanzania. These extended the origins of upright walking hominids back a million years before *Homo habilis*. Further discoveries of species and genera that existed before *A. afarensis* pushed back the frontiers of hominid existence to about 6,000,000 BP.



THE FOSSIL KNOWN AS LUCY Donald Johanson points out the 40 percent that has been found of the skeleton known around the world by her nickname of Lucy. The amazingly preserved *Australopithecus afarensis* specimen, which Johanson’s team discovered in the Afar region of Ethiopia, is more than 3,000,000 years old.

One of the more familiar species of hominid underwent considerable re-evaluation during this period. *Homo erectus*, the original “Java ape man” discovered before the end of the 19th century, was long thought to have originated in Africa, spread to Asia, and evolved directly into either *H. sapiens*, *H. Neanderthalensis*, or both. First, some anthropologists began to see differences between the most common Africans and the Asians and renamed the Africans *H. ergaster*. Then, a re-evaluation of the dates for *H. erectus* in Java suggested that this species was contemporary with early *H. sapiens*, and so could not be the ancestor. Finally, in Georgia, on the border between Europe and Asia, newly found skulls thought to be *H. erectus* further complicated the picture, suggesting that *H. erectus* had a larger and earlier place in Europe than previously supposed.

Another major change in this field was the advent and gradual acceptance of DNA analysis in sorting out the history of the early hominids. It was even possible to analyze DNA from Neandertal fossils, indicating that the Neandertals were a separate species.

ARCHAEOLOGY A series of discoveries, often controversial, pushed back the dates of the arrival of the first humans in the Americas. New theories emerged to explain the lack of pre-Clovis artifacts. One idea was that people from Asia who obtained much of their food from the sea traveled down the west coasts of the Americas before the Clovis hunters moved through Alaska into the Great Plains and Southwest of North America. But since the first immigrants lived mainly along coasts, rising sea levels since the end of the last Ice Age have obliterated most of the sites.

A major advance in the archaeology of the Americas was the deciphering of the written language of the Maya. This development, which was gradual and involved several different archaeolo-

gists, has enabled the history of the Maya rulers and their wars to be understood.

New tools for undersea exploration greatly expanded the knowledge of early ships and trade as well as of some early cities, such as parts of Alexandria, Egypt, that had slipped beneath the sea because of either subsidence or earthquakes or both.

ASTRONOMY For the first time astronomers during this period could get close-up pictures and measurements of planets, their moons, comets, and asteroids as space probes reached nearly every corner of the solar system. Although a few probes reached Venus and Mars, our nearest neighbors, and humans actually traveled to the Moon before 1973, the age of exploration of the planets really began with the Viking and Voyager missions of the 1970s. Other new optical views were obtained with sensitive charge-coupled devices (CCDs), which revealed, for example, dozens of additional tiny moons orbiting planets in the solar system.

After astronomers recognized that the Sun is a star, they began to think that the other stars might be suns to some system of planets like our own solar system. Even before the first extra-solar planet was discovered in 1995, science-fiction writers and people seeking signals of intelligent life elsewhere in the universe assumed that the planets must be there. It was difficult to prove, however, because stars are so much brighter than planets that the planets cannot be seen. The first detection of planets relied on tiny deviations in a star’s motion, recognized from the Doppler effect on light from the star, caused as a large planet orbits close to its star. After dozens of planets had been detected this way, astronomers were sometimes also able to observe dimming of light from the star as its planet passed between the star and Earth. A few systems of planets were

recognized as well as many individual large planets (all as large as or larger than the gas giants of the solar system). Planned new telescopes, especially space-based telescopes, will greatly improve the ability to detect smaller planets and perhaps even to image some of the nearer ones.

The first X-ray sources, including the first black hole candidate, Cygnus X, were discovered with low-resolution X-ray imaging systems equipped with collimating grids. The introduction of X-ray optics during the late 1990s allowed high-resolution images comparable to those obtained with optical telescopes. Two X-ray observatories, *XMM-Newton* launched by the European Space Agency and NASA’s *Chandra X-ray Observatory*, were equipped with conical grazing incidence X-ray telescopes that focused X-rays on sensitive CCDs. High-resolution images of the galactic center, for example, have provided evidence of a central black hole.

Also, infrared astronomy made progress. Telescopes placed high on mountains in dry areas, such as the Keck telescope on Mauna Kea in Hawaii and liquid-hydrogen-cooled telescopes placed aboard satellites, allowed astronomers to peek through the dust hiding the galactic center, revealing star-forming regions. In addition, the disks of dust and gas around stars — believed to be the birthplaces of planetary systems — were observed. Because the radiation of very distant galaxies is redshifted over a large amount, infrared telescopes also allow the observation of very distant galaxies that together contribute to the cosmic infrared background. This way astronomers have been able to peek at galaxies that formed about 1,000,000,000 years after the big bang.

Turbulence in the atmosphere that causes blurring of images (and twinkling of stars) was the main limitation of optical astronomy until the launch of the Hubble Space Telescope in 1990.

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Since that telescope was free of turbulence, astronomers obtained images with unprecedented resolution, revealing details never seen before, such as the glowing rings of gas now circling the star, gas that was ejected some 20,000 years before it exploded as a supernova in 1987. A new class of large ground-based telescopes also increased our view of the universe. Using adaptive optics, which consists of rapidly changing the shape of the main mirror by actuators linked to a computer for compensating the blurring caused by the atmosphere, allows Earth-based telescopes to attain resolutions comparable to that of the Hubble telescope.

After 1980 cosmology, enriched by the theory of inflation to explain the existing structure of the universe, became more than a theoretical science. Indeed, cosmology became something of an experimental science with the creation of computer models for the evolution of the universe. Using simulations run on large supercomputers with up to 1,000,000,000 mass points, astronomers obtained models for the clustering of galaxies that correspond to what is observed with large telescopes. Observations of the cosmic microwave background and also of very early galaxies enabled cosmologists to establish the age and explain many characteristics of the universe.

Astronomers began to observe galaxies that were formed when the universe was to about 10 percent of its age.

Cosmology has led to the view that the universe is more mysterious than we ever guessed. While the new windows opened up to astronomy allowed astronomers to see new classes of objects, astronomers also realized that an important part of the universe remained invisible — this invisible mass became known as dark matter. During the late 1990s astronomers found that a still unknown force, called dark energy, causes the expansion of the universe to

accelerate. About 95 percent of the universe is hidden from view either as dark matter or dark energy.

BIOLOGY The central focus of science and technology changes from period to period. It can be argued, for example, that astronomy was the central science of the 18th century, chemistry (and its related technology) of the 19th, physics of the 20th, and biology of the 21st (so far). Of course, there is a lot of overlap from century to century and major advances occur in all branches of science or forms of technology as well. Within the 20th century, physics was much more dominant in the decades of the 1930s through 1950s than throughout the century. Astronomy experienced some major advances during the 1920s, but space transportation became the key to the 1960s as humans went from the first few orbits at the end of the 1950s to the Moon before 1970. Biology gradually became more of a central science and created a central technology beginning in the 1950s with the recognition of the structure of DNA. By the 1970s more new developments were occurring in biology than physics, with the possible exception of the application of physics to cosmology.

We think of the unraveling of the genetic code in terms of first individual codons (the “letters” of the code) and then the genomes of bacteria, animals, and plants. A similar development, however, occurred earlier for viruses, which are almost all DNA or RNA. Well before the first organism based on cells had its genome unraveled, many viruses had been completely resolved at the DNA or RNA level — a simpler task, since virus genomes are comparatively small. Genetic engineering, which started in 1973, was immediately viewed with alarm by the biology community and strict rules were agreed to as early as 1974. Despite this concern, no proven harm has arisen from genetic engineering so far and some progress has been

made in medicine and agriculture as a result of the new technology.

Whole-animal biology, which has been less newsworthy than molecular biology and genetics, also advanced during the period. Helped in part by the new technology of DNA analysis, taxonomists have now identified six separate major groups of organisms, ranging from the Archaea (bacterialike creatures that occupy certain extreme environments) to the more familiar plants and animals. Several new species of large mammal were discovered in remote jungles, especially in Vietnam.

CHEMISTRY During this period the gradual merging of chemistry and physics continued, so many of the advances made by people who think of themselves as chemists now are designated as part of materials science. Similarly, the creation of new elements for the periodic table, one of the continued advances during this period, has been accomplished by physicists, not chemists.

In more traditional chemistry there were advances. Inorganic chemists were able to bring more of the noble gases into combination with other elements (notably fluorine), and new kinds of inorganic molecules, such as a nitrogen of four joined atoms, were formed. Organic chemists developed plastics that could be conductors of electricity or even superconductors as well as organic versions of the semiconductors that are basic to the electronics industry. The giant carbon molecules called buckyballs and nanotubes have been shown to have remarkable properties, often when some of the carbon atoms are replaced with other elements.

Applied chemistry continued to thrive. Chemists once noted whenever 1,000,000 more new compounds had been invented, but with more than 32,000,000 substances registered by the American Chemical Society and another 4000 added each day, it may not be until 100,000,000 are known before

chemists choose to remark on a milestone again.

COMMUNICATION The Information Age saw sweeping revolutions in communication, many, but not all, derived from computers. As their name suggests, the first computers were thought of primarily as very powerful calculators. Although early large computers were soon handling masses of data beyond simple calculation, the true possibilities of the tool in such fields as design and education were just beginning to become evident about the same time that the first personal computers were marketed.

When people began to play with their own computers, they soon found new ways to use the devices. Before 1973 there were no computer word processors or spreadsheets at all. By 1980 the personal computer had those plus a third major tool, the relational database — which, because of its generality, was more useful than the specific databases developed earlier for multiple-user computers. Similarly, the graphic programs for personal computers that followed word processing, spreadsheets, and databases brought a fourth new general tool into the mid-1980s. All four of these tools relieved the average computer user from programming chores.

One way computer use was simplified was by the introduction of pictures to replace words as control methods. The idea of using icons instead of complicated menus or commands goes back to 1973, although it did not become popular until the mid-1980s, and at that time only on the Macintosh computer family. Icons are small pictures displayed on the computer screen to suggest commands; for example, a file can be erased by using a mouse to drag the file folder over to a picture of a wastebasket and dumping it in. In the early 1990s, icons became the communication device of choice for most per-

sonal computers. Throughout this period, with the increasing likelihood of usefulness, voice recognition and production by computers (and other electronic devices) was the promised way to make operation of electronic devices even easier. Also, the keyboard — still something of an innovation as a data interface in the 1960s, despite the success of office typewriters and related instruments—was gradually being supplanted and sometimes replaced. In addition to the mouse, trackball, and touchscreen (for pointing and dragging), a number of computer manufacturers brought out input devices that accept stylized handwriting.

Not all changes in communication were directly linked to computers, although all had microprocessors embedded somewhere. The way light was used altered the world as well. Displays of all types were improved, a major revolution that went almost unnoticed. Light was used for storage in laser-based compact disks, or CDs, which, with improved technology, were reinvented in the form of DVDs (digital video — later versatile — disks). The CD, invented for recording music, and the DVD, invented for recording movies, soon were both adapted for recording information of all types.

Related to several of the trends in communications was the continued shift from analog to digital or, perhaps more accurately if not colloquially, from continuous data to discrete data. At first only computers were digitalized. Today, CDs and related tape recording methods use digital sampling to approximate continuous sound very effectively and astronomers and space probes use digital techniques to approximate continuity in images. First satellite television and then cable television moved into digital television, enabling many more channels and higher definition than analog versions.

Computerized telephone switching

displaced the large majority of electro-mechanical switching systems developed during the first decades of the 20th century, and the cellular telephone networks that sprung up all over the world were only possible because of cheap and massive computing power that became available. Paradoxically, cell phones were in many cases a better communication solution in developing areas that still had not build up a communications infrastructure. The most important advance in existing communications infrastructure was the worldwide replacement of copper and coaxial cable by optical cable. As a result communications satellites lost some of their importance for long-distance telephone links, but became important as transmitters for television programs beamed directly into the homes equipped with satellite dish antennas.

The Internet originated as a network developed by the U.S. Defense Advanced Research Projects Agency (DARPA) during the early 1970s. The original goal was that data transmission would not depend on single computer centers but would be widely distributed so it could survive attack on any single part of the network. During the 1980s, the network was extended to include research institutions and universities, and quickly the Internet became available to the wider community. While in the beginning it served as a convenient way for instant communication, it quickly outgrew this phase. With the introduction of graphics capabilities and of the World Wide Web, the Internet became not only the backbone for new businesses, but it became a full-blown medium itself. Newspapers and magazines started publishing on the Web, and quickly e-zines, magazines existing only in electronic form, and repositories of personal writing called “weblogs,” or simply “blogs,” made their appearance. The new medium also caused problems with existing

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copyright provisions when authors, photographers, and music publishers found their creations becoming freely available on the Web.

Data acquisition, especially in the sciences, has increased enormously. For example, the amount of astronomical data gathered by automated telescopes now largely exceeds the capability of astronomers to study them. A typical search engine can now access several billion Web pages. New techniques include data mining, artificial intelligence, and so-called “personal assistants,” software that learns which type of information a user is using.

Astronomers now have created so-called virtual observatories, such as the National Virtual Observatory (NVO) in the United States, grouping about a dozen astronomical databases, huge electronic archives that contain data of the Hubble Space Telescope and other telescopes, and that can be accessed for research with specially created data-mining software. For example, one search in the NVO database resulted in the discovery of a rarely seen celestial object, a brown dwarf, in 2003.

COMPUTERS For most people, the Information Age is intimately tied up with the sudden rise of the personal computer. Although it may not have become the home appliance envisioned by many at the start, the personal computer, just a gleam in the eye in 1973, has become essential to office operations of all types in advanced industrial nations, especially in the United States and Canada. Each year new versions appear, faster and with more capabilities than those of the year before. The new personal computers are smaller and lighter each year, and more and more workers find that the laptop or notebook computer that they carry with them from place to place is most useful for their purposes. Such small computers have become so advanced in design that many people prefer to use

them instead of similarly equipped desktop computers even when working in the same place each day.

Since 1975 the most powerful computers have been so much faster than the kind employed by ordinary businesses that they are called supercomputers. The supercomputers’ great speed is essential in such tasks as modeling complex change or designing complicated parts. Even as the supercomputers were becoming faster and more complex, an entirely different idea surfaced. Instead of putting every scrap of information though a single microprocessor at a faster and faster pace, one could use a number of microprocessors working on different parts of the same problem to gain speed. Computers built this way, which is called massively parallel architecture, have already outsped some the fastest supercomputers for some kinds of problems. The future, however, probably does not belong to either type alone, as some problems resolutely resist breaking into the bits and pieces used by massively parallel computers.

Another route to computing speed has been to utilize the speed of light, faster than the speed of an electric current in a wire. Light also has other advantages. Electrons are fermions, which means that two of them cannot be in the same “place” at one time. Light particles are bosons, happy to share the same place with each other. As a result, it is much easier to design light-based equipment in which everything happens more or less at once. Although the technical problems seem to be formidable, there has been considerable progress toward the all-optical computer.

There is also much talk about the future of quantum computers, machines that would use quantum effects to process information based on the ability of isolated subatomic particles to occupy two or more states at the

same time. The once-esoteric concept of entanglement is the basis of this new extension of quantum theory, which some have dubbed quantum information science. The “old” information theory, first formalized in 1948, dealt primarily with numerical versions of information, although its application to communication involved physical switches and signals. Quantum information science recognizes that all information is actually physical (even numbers are not information until physically encoded in some way). When the physical information can be kept from any contact with the world at large, which is only possible for very small particles such as electrons or photons, the information obeys the laws of entanglement instead of the laws that apply to larger entities.

The particles of quantum information science are called qubits (pronounced “cue-bits”). Qubits, unlike the ordinary bits of classical information theory that can only be on or off, can exist in very many — perhaps an infinite number of — superimposed states at once, although only one of these states can be observed at any time. But several qubits can be entangled, allowing the possibility of operating on all the stored states at once. Since 1994 the theory of managing qubits to compute solutions to otherwise intractable problems and to retrieve those solutions without error has been developed. The near future should see some physical versions of a quantum-based computer in laboratories at least, with useful versions still some years away. Even if obstacles develop that prevent the quantum-based computer from becoming a reality, the theory of quantum information science is expected to yield new insights into particle physics and materials science.

CONSTRUCTION Change tends to take place slowly in architecture, even when everything else seems to have been

speeded up. Since 1973 the main changes have been stylistic — away from the purely functional and unadorned — and size-related. Early in the Information Age the world got a new tallest building in the Sears Tower in Chicago, Illinois, and a new tallest structure in the CN Tower of Toronto, Canada. The Sears Tower was surpassed, however, by tall buildings from Asia, and now the Taipei Financial Center in Taiwan, at 508 m (1667 ft), completed in 2003, is the tallest. Even the world's largest church, which had been St. Peter's in Rome since 1626, was exceeded in size. The characteristic new shelters of the Information Age, in North America at least, were indoor malls. These too reached sizes that far surpassed any shopping areas previously built, especially in northern climates, where spending a day out of the winter cold was an attraction in itself.

The attacks on the tall World Trade Center (WTC) towers on September 11, 2001, however, revealed the vulnerability of tall buildings. Terrorists crashed passenger planes loaded with fuel into the upper stories of each of the two towers. Because of the way that the WTC towers had been constructed, when flames from burning jet fuel melted steel girders on the upper floors where the planes had struck, these floors collapsed and the weight of the floors above then collapsed all the floors below. In a matter of seconds, each of the towers was reduced to a pile of rubble, killing nearly all of the 3000 or so persons still inside the buildings.

EARTH SCIENCE The discovery of the worldwide iridium layer in 1980 that led to the recognition that a giant impact in what is now Yucatán caused the extinction of the dinosaurs was the biggest single story of the period in earth science. Other impacts were found that may have had similar effects, and even the great Late Permian

extinction may have originated in an impact by an asteroid or comet.

Dinosaurs were in the news a lot, despite their apparent extinction some 65,000,000 years ago. The word "apparent" is needed because many paleontologists have come to believe that birds are modern dinosaurs, a belief reinforced by the discovery during this period of dinosaurs with feathers. Many fossils of dinosaur eggs found during the period reveal more about the social life and growth patterns of dinosaurs, while the range of dinosaurs was extended both north and south nearly to the poles.

The giant El Niño climate changes of the 1980s started meteorologists on a quest to determine how changes in the temperature of the South Pacific affect weather around the world. The use of cores from both the ocean floor and the ice caps revealed much about past weather cycles, causing scientists to begin to focus on changes in the North Atlantic as well as the South Pacific.

Geologists continued to use volcanoes and earthquakes to study the interior of the planet and also to use the theory of plate tectonics to explain volcanoes, earthquakes, and the arrangement of the continents. The core of Earth was shown to be irregular in shape, and its composition and effect on Earth's magnetic field, which during the period began to show signs of reversing polarity, were studied.

ECOLOGY & THE ENVIRONMENT The early part of this period was a high-water mark for the environmental movement in Western countries. In the United States, the 1970s and early 1980s gave birth to laws intended to clean up the environment, protect endangered species, and restore wilderness regions. A major change in the scope of the problems faced was simply that environmental problems had gone global. Early in the period scientists recognized that the use of certain chemicals was

destroying the protective ozone layer in the upper atmosphere, permitting the increase of harmful ultraviolet radiation. Gradually throughout the period, scientists became increasingly convinced that another atmospheric human-induced change, the rise of greenhouse gases, was producing global warming with unknown consequences.

As the 1980s progressed, the dichotomy between economic progress and environmental concerns became more prominent. Third World countries wanted the industrial nations to stop polluting, but they also wanted to develop polluting industries for their own nations. Still, at the end of the 1980s, the first major agreement on a global environmental issue, halting the production of chemicals that damage the ozone layer, was set among 13 industrial nations, with no Third World participation. By the early 1990s, many of the differences between economically underdeveloped countries and the wealthy nations were partially resolved in important international conferences, notably the Earth Summit in Rio de Janeiro, Brazil, in 1992 and a major agreement on fighting global warming at Kyoto, Japan, in 1997. During the 1990s also the Intergovernmental Panel of Climate Change met under United Nations auspices to continue the study of global warming, reporting increasingly strong evidence that climate change was occurring and that humans had caused it.

ELECTRONICS It is easy to forget that modern electronic devices go considerably beyond the computer. Everything from ATMs and automobiles to vacuum cleaners and washing machines is built today with microprocessors that act as small, special-purpose computers inside more traditional machines. The subtle effects of this transition from the mechanical to the electronic are not always perceived by users until one of the devices breaks down and a chip has

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to be replaced. For the most part, however, the embedded microprocessors simply make old functions happen better and more smoothly.

While Moore's law — the prediction that the number of components in a chip per surface unit will double every 18 months — has remained valid, and is expected to be true for years to come, researchers are investigating ways to create circuits that would allow even greater densities. A new field, called molecular electronics, has emerged. Scientists have shown that nanotubes and even single molecules can serve as transistors or switches. At the same time, researchers have been looking for ways to replace silicon as a semiconducting material in electronic circuits. Organic semiconductors may be less expensive to fabricate, require fewer polluting or dangerous chemicals, and even be made into flat and flexible sheets of plastic.

ENERGY Use patterns of energy in the developed world changed dramatically starting in 1973, the year of the first crisis caused by the Organization of Petroleum Exporting Countries (OPEC). The OPEC oil embargo steeply raised prices of petroleum and products based on petroleum. A second OPEC action in 1978 led to even higher prices that have remained at their new level since. Although the initial shock of the higher prices and petroleum scarcity caused governments to attempt to find alternative fuels and to promote fuel conservation, the novelty wore off, and new oil finds in Alaska and the North Sea contributed to a return to the status quo of using high-priced oil recklessly.

The nuclear accidents at Three Mile Island in Pennsylvania and Chernobyl in the Soviet Union cast a pall over the use of nuclear reactors for power. No new nuclear reactors for production of electric power have been commissioned in the United States since the Three

Mile Island disaster in 1979, and a few have been put out of service as a result of age. Nuclear reactors are recognized as good in the sense that they do not use fossil fuels or contribute to air pollution when they are working properly. On the other hand, they are feared because of the possibility of accidents, and they produce waste that is almost impossible to store safely. Consequently, there has been a serious effort to search for a better way to produce energy. Nuclear fusion has long been held out as that way, but little progress has been made in developing it in the past 20 years.

Although a number of innovative alternatives to nuclear power and fossil fuel were pursued, including everything from improved old-fashioned windmills to high-tech means of tapping the difference in temperature between the surface and the depths of the ocean, the main alternative that has continued to grow in use, efficiency, and theory is solar power. Each improvement in solar cells, which convert sunlight to electricity directly, is widely heralded, but actual applications of the new technology have proven too costly for widespread use so far, except in watches, calculators, and similar low-energy devices that work well with existing solar cell technology.

Fields of efficient windmills, called wind farms, increased their contribution to the electric grid during this period. Unlike many alternative sources of energy, wind farms came close to being economically viable (and were profit-making with a little help from the government). But there was considerable concern about their lack of visual appeal and some worry about effects on wildlife. Another economically viable alternative, especially in certain regions of the world, was geothermal heating, which would also be used to produce steam for generation of electricity.

FOOD & AGRICULTURE Food for health was on people's minds in Western soci-

ties. People were afraid at one time or another to eat sugar, fat, meat, cholesterol, raw fish, salt, solid margarine, high-glycemic carbohydrates, all carbohydrates, even apples (that had been sprayed with the chemical Alar). In a counterpoint to the feared foods, people were encouraged to consume such foods as oat bran, olive oil, fish, broccoli, dark-green vegetables, orange vegetables and fruits, and even red wine and foie gras in large quantities. The primary reason for the new mandates, which seemed to change on a weekly basis, was better health. Although the guidelines were confusing, health statistics suggested that for those trying to follow them, some overall benefits were occurring.

A whole different set of prejudices revolved around what the food was put in before it was eaten. The fast-food chains that had come to be a major influence on diet were a common target of packaging reform, with the McDonald's chain switching its packaging for burgers several times in hopes of satisfying both environmentalists and hungry customers. The debate between those favoring foam plastic cups and those favoring paper cups was never fully resolved.

But the biggest debate, especially in Europe, concerned food that had in part or completely been produced from plants that had been developed by genetic engineering. Genetically modified (GM) food became a big issue with the public and even some scientists warned against its danger. Some nations refused to accept GM food at all, even in the face of famine.

The original GM foods that made headlines were tomatoes with a longer shelf life and other fruits that might be purchased at a supermarket. But the true story of GM food was happening on the farm, where farmers quickly took to corn, soybeans, or cotton (not food, of course, except the seed and

then mainly for animals) that had been modified to resist pests. In a few short years, much of American grain, beans, and fiber were of GM pest-resistant varieties. These were not sold in stores directly, but became the basis of the corn syrup, soy flour, and animal feed that is less directly part of the modern food chain. Elimination all GM food is today practically impossible in the United States — although new labeling has made organic food more available and organic food does not permit genetically modified ingredients even indirectly.

MATERIALS Two totally unexpected types of material have dominated technology news since the mid-1980s. One is a class of ceramics that becomes superconducting at temperatures much higher than those known earlier. The other is a class of carbon molecules and compounds that is typified by a molecule of buckminsterfullerene — the buckyball, a carbon molecule of 60 atoms in the shape of a soccer ball.

Superconductors are, as their name suggests, materials that conduct electricity with no resistance at all. They also have other unusual electromagnetic properties. The first superconductors to be found were metals that became superconducting near absolute zero for reasons that are now well understood. Ceramic superconductors can perform at temperatures as much as 100°C (180°F) higher. Although such materials have great possibility as the base of a new technology, this potential has failed to be realized because of difficulties in fabrication and other problems. Another material that is superconducting was a big surprise to materials sciences. Magnesium diboride is not an exotic ceramic and can be found in regular chemical supply houses, but it is a superconductor below 39 K.

The large carbon molecules are called fullerenes when they are pure carbon. Because of the way carbon

atoms bond to each other, fullerenes are various shells surrounding empty space. In the laboratory fullerenes and related compounds have done such wonderful feats as superconducting and forming diamonds. For many potential applications the preferred form of carbon is not the spherical buckyball but molecules in the shape of tiny tubes, called nanotubes.

MATHEMATICS Early in the period the proof of the conjecture about how many colors are needed for a map on a plane so that no countries with common boundaries have the same color (four) was proved by computer analysis. This presaged two of the main trends of the period, the many proofs of old (and also more recent) conjectures as well as the use of computers by mathematicians in proofs and in finding new theorems to prove. The most famous conjecture (known as Fermat's Last Theorem, although since Fermat's supposed proof has never been found or reconstructed it can be classed as a conjecture) proved during the period was proved the old-fashioned way, however, without computers. Its proof relied on a tool of great importance in algebra and number theory, the theory of elliptic curves. But mathematicians were still arguing in 2003 about whether Thomas Hales's computer proof of a Kepler conjecture is valid, since the computer program was so complex that a team of mathematicians found themselves unable to check it.

MEDICINE & HEALTH Increased access to information about a patient's inner state was a key development in medical technology in this period. New in the early 1970s, CT (computed tomography) and MRI (magnetic resonance imaging) scans became, especially in the United States, routine noninvasive procedures for all sorts of medical problems. Each uses complex mathematical techniques to reconstruct clear views of internal organs, with the CT

scan relying on a version of conventional X rays and the MRI scan using a newer technology in which magnetic forces cause individual atoms to broadcast radio waves that can be detected outside the body. To some degree the new technologies are complementary, since CT scans are better for looking at bones, while MRIs can image soft tissues that are transparent to X rays.

Gradually, genetic engineering has gone from the laboratory into the clinic. Although still not everyday medical practice, except for some substances produced by genetic techniques, more and more chronic or congenital diseases were in experimental treatment by genetic-based methods during the 1990s and early 21st century. With the decoding of the human genome, genetic therapies are likely to become more effective. One concern is that some genetic treatments have caused new diseases in the person being treated — sometimes fatal ones.

Another new development has been the application of monoclonal antibodies, discovered in 1975, after many years of promise with no results, to a successful treatment for breast cancer. This development bodes well for the future of monoclonal antibodies that can lock onto specific proteins and deliver medicine where it is needed.

Transplant therapy continued to improve throughout the period. Also, continued work with stem cells has suggested the possibility of tissue transplants that can replace any part of the body in ways that do not provoke the immune system. Bone marrow transplants are the beginning of this trend. Both embryonic and adult stem cells offer much hope for the future.

Despite these developments, a continuing thread in health throughout the period was the emergence of new diseases carried by viruses or less frequently by bacteria. The most devastating of these, AIDS caused by the HIV

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virus, was recognized in 1981. It still can only be controlled, not cured. With air travel between continents common, new diseases often spread quickly around the world, as SARS did in 2003.

PHYSICS Research in physics can be characterized by the venturing further into the exotic states of matter, far away from the conditions of matter and energies we experience in daily life. Particle accelerators increased in size enormously. The Large Hadron Collider (LHC), scheduled to begin operations in 2007, will use 6000 superconducting magnets in a circular tunnel 27 km (17 mi) long. It will collide particles with energies close to those that reigned shortly after the big bang. Some experiments at smaller particle accelerators have already indicated the creation of the so-called quark gluon plasma — an exotic state of matter consisting of free-roaming quarks and gluons. Experiments with these large colliders, including the Tevatron and SLAC, have generally confirmed the so-called “standard model” of particles and fields, verifying the existence of several particles, such as quarks and the W and Z bosons. Indeed, by 2003 all of the ordinary particles predicted by the standard model had been located. However, the existence of one extraordinary particle predicted by the standard model, the Higgs boson, the particle thought responsible for giving other particles their mass, has not yet been demonstrated. Another prediction by the standard model, that neutrinos have no mass, proved wrong. Observations of neutrinos coming from the Sun and from particle accelerators showed that neutrinos have mass, although very small as compared with other particles. However, their combined mass may be sufficient to make up a substantial part of the dark matter in the universe. A few interactions have been observed that suggest that the standard model may need other revisions.

Whether antimatter exists naturally somewhere in the universe remains an open question, but researchers at CERN succeeded in producing small amounts of antihydrogen atoms. Another exotic form of matter was obtained in the mid 1990s when researchers created the first Bose-Einstein condensate (BEC), atoms cooled down to such low energies that they form a single “super atom.” The existence of such condensates had been predicted by Albert Einstein and Satyendra Bose during the mid-1920s.

Advances in experimental techniques allowed the testing of several of the tenets of quantum mechanics. Scientists demonstrated the simultaneous appearance of two superimposed quantum states in individual atoms — this situation immediately disappears when the system couples to the environment. This phenomenon is called quantum decoherence, and physicists view this phenomenon now as the link between the quantum world (with its laws that we cannot visualize) and the macroscopic world that we see around us. Scientists plan to use the superposition of states for the creation of quantum computers.

Many physicists worked hard during this period on theories that have not been able to be tested so far. Although the standard model of particle physics has been very successful, it is hard to reconcile with gravity as explained by Einstein’s theory of general relativity. Also, theories that treat particles as strings in several (typically 11) dimensions have proven to be more tractable mathematically than describing particles as points, waves, or small regions in space. When physicists discovered a version of string theory that also predicts partners for every known particle (called superstring theory) and that is also easy to reconcile with gravity, many turned to working out the details and implications — which led to a further interpretation in terms of mem-

branes (or branes) embedded in spaces of higher dimensions. Although none of these theories has been testable as yet, it is widely believed that some version of brane theory will be found true at higher energies than current particle accelerators can produce.

TOOLS The most exciting tool of the period was the laser, which continued to be a source of new ways to do old things and to accomplish some goals no one had dreamed of previously. Lasers very quickly moved from science museum demonstrations and light shows at rock concerts into homes, factories, and hospitals. Retail merchandising changed with the laser scanner, and new uses for the Universal Product Code, that pattern of lines read by a scanner, emerged throughout the period. Often the only way that a user would recognize that a laser was involved was if the word was used in the name, as in a laser printer. Laser printers replaced not only the impact printers used with home computers, but many of the typesetting machines used for producing books and magazines. Laser printers combined with innovative software made everyone potentially a publisher, although the real advantages of desktop publishing were primarily commercial in terms of speed and cost.

Another major development that has had unexpected applications is the scanning tunneling microscope and its various spinoffs. Not only has this tool and the closely related atomic force microscope revealed details about surfaces, molecules, and atoms that were once thought to be forever beyond imaging, it has also led to tools that manipulate individual atoms or molecules. The full force of this technique is yet to come, but technology appears to be nearing a point predicted by Richard Feynman in the late 1950s when useful devices can be built from a number of molecules that can be counted on the fingers of

two hands. This trend has been dubbed nanotechnology, since it includes parts thousands of times smaller than those of the microtechnology that powered the United States space effort and led to the notebook computer. Nanotechnology has become one of the major developments in new ideas and experiments, but it is just beginning to affect articles and devices used in ordinary life.

TRANSPORTATION Transportation in this period revolved around the old bridal tradition of "something old, something new, something borrowed, something blue."

An old idea brought back from the brink of extinction was the passenger train, speeded up by conventional means in Japan and France with new computerized technology for better cornering available from Sweden. Trains appear to be more efficient than airplanes for moving people and goods intermediate distances. In the United States and England, however, the extensive network of and investment in old track seems to be holding back development in this area. In Germany and Japan various experimental trains, called maglev trains, have used a system with the cars suspended from the track and propelled by magnets. Plans exist for a 148-km (92-mi) maglev system for southern California, a 76-km (47-mi) project in the Pittsburgh, Pennsylvania, region, and a 64-km (40-mi) system connecting Baltimore and Washington. But the first to have regular passenger service is China, which

opened a 30-km (19-mi) line between Shanghai and its airport in 2003.

Perhaps the oldest idea of all is human-powered transportation. Human-powered flight became a reality in the Information Age, although it was not widely used. Human-powered bicycles, however, remained the most widely used mechanized transport system worldwide.

The reusable space shuttle of the United States is something new, but it is a troubled means of transportation. It almost seems as if the more experience people have with the shuttles, the less reliable they become. By the early 1990s there was a movement to find better ways to get into and out of near-Earth space, a movement that accelerated after the loss of the space shuttle *Columbia* and its crew in 2003.

Environmental concerns caused a number of automobile manufacturers to borrow and update almost every idea ever tried for replacing the gasoline engine in motor cars with some other means of propulsion — except perhaps the steam engine. Although none of the experimental vehicles had reached the general public by the early 1990s, plans were under way for electric cars and internal combustion engines powered with methane or other non-gasoline hydrocarbons before the end of the decade. But the first successful new cars were hybrids, powered with both small gasoline internal combustion engines and separate electric engines. Batteries

for the electric engines in the hybrids are powered by using energy from the wheels as the car slows or is braked. The result is a car that does not have to be plugged in and that has double or triple the gas mileage of a conventional car.

Electric automobiles powered by fuel cells instead of batteries, a brand new technology, may take a little longer to reach the roads, although they were promoted by the George W. Bush administration in the United States. Although the fuel cell is well over a hundred years old, its only use in transportation so far has been to power devices aboard U.S. spacecraft in the 1970s. Experimental solar-powered electric cars have also been tested, notably in competitive races in Australia and the United States.

Transatlantic passenger ships were victims of the development of civilian airlines. During the 1950s and early 1960s ocean liners still could compete with airlines, but they practically disappeared during the 1970s. Several famous large passenger ships, such as the *France*, were converted into cruise ships, starting them on new, successful careers.

The blue and deep black under the seas is being explored by a new generation of submersible devices, some with human pilots and some with robots. These devices are revealing not only new facts about life and geology at the bottom of the sea, but also are photographing or retrieving parts of old shipwrecks.

CHRONICLE

1973

★ Astronomy

Ray Klebesadel, Ian B. Strong, and Roy A. Olson of Los Alamos National Laboratory report the discovery by the

Vela satellite of gamma-ray bursts originating in outer space. The satellite was searching for gamma-ray bursts caused by nuclear explosions on Earth. See also 1997 AST.

John Hershey shows that the telescope used by Peter van de Kamp to find a wobble in Barnard's star, indicating the

presence of a planet, also causes wobbles in the motions of 12 other stars, throwing doubt on the hypothesis of a planetary system at Barnard's star; other astronomers also fail to detect wobble. See also 1962 AST; 1995 AST.

Gamma rays are detected from an "invisible" source,

termed in 1976 "Geminga" by Giovanni Bignami (in the Milanese dialect "geminga" stands for "it's not there"). See also 1987 AST.

Jeremiah Ostriker and James Peebles [b. Winnipeg, Canada, April 25, 1935] determine that dark matter must occur in large halos surrounding spiral galax-

ies to prevent the galaxies from flying apart. Visible matter makes up only about 10 percent of the material needed to keep galaxies stable. They propose that the galactic halos consist of some unknown particles that do not interact electromagnetically but that are affected by gravity and move relatively slowly (known as cold dark matter). *See also* 1985 AST.

Pioneer 10 (U.S.) is the first spacecraft to visit Jupiter, passing within 130,000 km (81,000 mi) of the planet. *See also* 1972 AST.

The U.S. launches *Pioneer 11*, the first space probe to reach the vicinity of Saturn. *See also* 1962 AST; 1977 AST.

On November 3 the U.S. launches *Mariner 10*, the first space probe to observe two planets, Venus and Mercury, and the only probe ever to observe Mercury. *See also* 1962 TRAN; 1974 AST.

Biology

Stanley Cohen [b. Brooklyn, New York, November 17, 1922] and Herbert W. Boyer [b. Pennsylvania, 1936] perform the first experiments in genetic engineering. DNA molecules are cut with restriction enzymes. Then pieces of the DNA are inserted into the bacterium *Escherichia coli*, where they perform as new genes. *See also* 1972 BIO; 1974 BIO.

Timothy V. P. Bliss and Terje Lømo find that high-speed bursts of electricity strengthen neural networks in the brain, tending to confirm the neural-network theory of memory proposed by Donald Hebb. *See also* 1949 BIO.

Jared Diamond's "Distributional Ecology of New Guinea

Birds" claims that similar birds occur in a gradation in which each larger bird is about 1.3 times as large as its smaller relatives in all dimensions. Later work shows that this ratio also applies to inanimate objects such as skillets and violins so it is not a biological principle.

Chemistry

Ernst Fischer of Germany and Geoffrey Wilkinson win the Nobel Prize in chemistry for their work on the chemistry of ferrocene. *See also* 1951 CHEM; 1952 CHEM.

Communication

Robert Metcalfe [b. Brooklyn, New York, 1946] invents Ethernet, a network in which data are transmitted in packets. *See also* 1975 COMM.

Thomas B. Martins and R.B. Cox develop a system that allows a computer to understand spoken commands. *See also* 1968 COMP; 1975 COMM.

The British Post Office starts up a data service for the public called Prestel. It supplies data from a large number of organizations and businesses via television screens. *See also* 1980 COMM.

Fairchild Semiconductor commercializes the first CCD (charge-coupled device) imaging chip of 100 by 100 pixels. Such devices will replace photographic film for recording observations by astronomers and later become the basis of digital cameras. *See also* 1974 AST.

Computers

Alan Kay develops the first "office computer," the ALTO, at Xerox's Palo Alto Research Center (PARC). ALTO is based on the SMALLTALK software,

and features the use of a mouse, icons, and graphics. Only 1200 will be produced in part because each one costs \$15,000 to build. *See also* 1972 COMM; 1974 COMP.

In France the Micral personal computer, designed by François Gernelle and based on the Intel 8008 microprocessor, is the first personal computer to go on sale, although at \$1750 it does not have much impact. *See also* 1974 COMP.

The ENIAC patent is invalidated, crediting John Vincent Atanasoff [b. Hamilton, New York, October 4, 1903, d. New Market, Maryland, June 15, 1995] as the originator of the modern computer. *See also* 1945 COMP.

Construction

On May 3 the Sears Tower in Chicago, Illinois, becomes the tallest structure in the world, surpassing the World Trade Center in New York City. The Sears Tower reaches a height of 442 m (1450 ft). *See also* 1972 CONS; 1974 CONS.

Earth science

A fissure volcano on the island of Heimaney off Iceland erupts and nearly buries the town of Vestmannaeyjar. By pumping some 8,000,000 tons of seawater over the lava, volunteers from all over Iceland manage to cool the lava enough to save the town, the first successful intervention in preventing damage from an erupting volcano. *See also* 1960 EAR.

Ecology & the environment

The first U.S. Endangered and Threatened Species List is issued by the Fish and Wildlife Bureau, identifying animals

and plants that are in danger of becoming extinct. Also, 80 nations sign the Convention on International Trade in Endangered Species (CITES), which prohibits commercial trade in endangered species. *See also* 1966 ECOL; 1977 ECOL.

Karl von Frisch and Konrad Lorenz of Germany and Niko-laas Tinbergen of the Netherlands win the Nobel Prize for physiology or medicine for their study of individual and social behavior patterns of animal species. *See also* 1950 BIO; 1966 ANTH; 1953 ECOL.

Electronics

Ten thousand components are placed on a chip of 1 cm² (0.16 sq in.) using a technique termed Large Scale Integration (LSI). *See also* 1965 ELEC; 1974 ELEC.

Food & agriculture

Ian Wilmut [b. Hampton, England, September 9, 1944] and coworkers are the first to produce a calf from a frozen embryo. The calf is named Frosty 2 (Frosty 1 was the first calf from frozen sperm). *See also* 1951 FOOD; 1984 MED.

The push-through tab on soft drink and beer cans is introduced. *See also* 1963 FOOD; 1975 FOOD.

Mathematics

Charles H. Bennett proves that it is theoretically possible to build a computer without the known components that cause a loss of energy.

Brian Kernighan and Shen Lin find a useful algorithm for solving various cases of the traveling salesman problem, one of the classic difficult conundrums of mathematics and a paradigm for an entire

class of problems. The basic task is simple: A salesman needs to plan his route between n cities so that he visits each one exactly once and travels the shortest possible distance. As n increases, the problem becomes vastly more difficult. *See also* 1988 MATH.

♥ Medicine & health

Michael S. Brown [b. Brooklyn, New York, April 13, 1941] and Joseph L. Goldstein [b. Sumter, South Carolina, April 18, 1940] discover the receptor in the membrane of human body cells that captures low-density lipoproteins and removes them from the bloodstream, an important step in understanding how atherosclerosis (arterial plaque) develops. *See also* 1964 BIO; 1985 MED.

⌘ Physics

Paul C. Lauterbur [b. 1929] of the State University of New York at Stony Brook creates two-dimensional images with nuclear magnetic resonance by using a graded magnetic field that upon relaxation releases radio waves. His first somewhat fuzzy images are of water in small glass tubes, and the paper on the subject is initially rejected by the journal *Nature* as trivial. After publication, however, the method is recognized as an important step in the development of the technique of magnetic resonance imaging (MRI), a useful tool for obtaining images of specific tissues in a living body without harming the body. *See also* 2003 MED.

Hans G. Dehmelt [b. Görlitz, Germany, September 9, 1922] and assistants Philip Ekstrom and David Wineland succeed in capturing a single electron and

holding it in place (in a device called a Penning trap) for as long as ten months at a time. *See also* 1936 ELEC; 1980 PHY.

Paul Musset and coworkers at CERN discover weak neutral currents in neutrino reactions; these had been predicted by the electroweak theory and are viewed as a partial confirmation of the theory. *See also* 1983 PHY.

David Politzer and, independently, David Gross and Frank Wilczek [b. New York City, May 15, 1951] show that quarks must exhibit asymptotic freedom — that is, the farther apart quarks are, the more they attract each other. When quarks are touching, they ignore each other. *See also* 1961 PHY.

Jogesh C. Pati and Abdus Salam suggest theoretical reasons why protons might decay into other particles.

Julius Wess and Bruno Zumino write the first of their papers laying the foundation for the theory of space-time supersymmetry, an extension of special relativity that results in a theory of supersymmetry in four dimensions. Supersymmetry, which will be given that name by Abdus Salam and John Strathdee in 1974, postulates that for every fermion there is a bosonic partner and similarly for each boson there is a partner that is a fermion. These partners, which are thought to be massive, will not be observed by 2003, although many physicists continue to believe in their existence.

Kenneth G. Wilson [b. Waltham, Massachusetts, June 8, 1936] analyzes phase transitions of materials in several dimensions using quantum field theory. *See also* 1982 PHY.

Leo Esaki of Japan, Ivar Giaever, and Brian Josephson win the Nobel Prize in physics for their theories on superconductors and semiconductors important to microelectronics. *See also* 1957 PHY; 1960 PHY; 1962 PHY.

I Tools

Scientists at Bell Labs develop a tunable, continuous-wave laser.

→ Transportation

The first space station, the unmanned *Skylab* (a.k.a. *Skylab 1*), is launched by the United States on May 14 atop a Saturn V rocket. The first three-man crew of Charles Conrad, Jr., Joseph Kerwin, and Paul Weitz is launched aboard *Skylab 2* on May 25. Their vehicle docks with *Skylab*, makes repairs, and conducts medical and other experiments, staying in space for 28 days. The *Skylab 3* mission is launched on July 29 and lasts 59 days. Astronauts Alan Bean, Owen K. Garriott, and Jack R. Lousma perform systems and operational tests and thermal shield deployment. Astronauts Gerald P. Carr, Edward G. Gibson, and William R. Pogue are launched on November 16 in the *Skylab 4* mission; during this 84-day mission, the crew performs unmanned Saturn workshop operations and obtains medical data for extending spaceflights. *See also* 1979 TRAN.

Soviet cosmonauts Vasily G. Lazarev and Oleg G. Makarov begin a two-day *Soyuz 12* mission on September 27; this is the first Soviet spaceflight to carry humans since the *Soyuz 11* tragedy. Cosmonauts Pytor I. Klimuk and Valentin Lebe-

dev begin the *Soyuz 13* mission on December 18; they perform astrophysical and biological experiments during the eight-day mission.

The *Train à grande vitesse* (TGV), a high-speed train, begins experimental runs in France. *See also* 1964 TRAN; 1981 TRAN.

1974

◀ Anthropology

A team led by Donald Johanson and French geologist Maurice Taieb discovers "Lucy," 40 percent of the skeleton of an early hominid that is 3,300,000 years old. Lucy is a representative of a previously undiscovered species, *Australopithecus afarensis*. *See also* 1960 ANTH; 1975 ANTH.



Donald Johanson

[b. Chicago, Illinois, 1943]

Donald Johanson became famous as the co-leader of the team that in 1974 discovered in Ethiopia the first specimens of *Australopithecus afarensis*, including the 1974 find of "Lucy," a 40 percent-complete fossil from 3,300,000 years ago. The year before Johanson had found the first known knee joint of any prehuman hominid, which provided the first hard evidence of upright stance. In 1975 his team found a large collection of *A. afarensis* fossils and the following year the oldest known stone tools, dating from 2,500,000 years BP. He founded the Institute of Human Origins in 1981.

★ Astronomy

Stephen Hawking shows that black holes radiate particles, causing the black holes ultimately to evaporate. This is called Hawking radiation. *See also* 1967 AST; 1980 AST.

Russell Alan Hulse [b. New York City, November 28, 1950] and Joseph Hooton Taylor, Jr. [b. Philadelphia, March 24, 1941] discover the first binary pulsar and calculate that the two components approach each other because the system is radiating energy in the form of gravitational waves. *See also* 1980 AST; 1993 AST.

The first astronomical image with a charge-coupled device (CCD), the Moon, is obtained with a 100 by 100 pixel CCD made by Fairchild Semiconductor. *See also* 1973 COMM; 1975 AST.

Antoine Labeyrie [b. May 12, 1943], in Nice, France, creates the first two-telescope optical interferometer, primarily to prove that the method can work. *See also* 1868 AST; 1984 AST.

Robert Wagoner, William A. Fowler [b. Pittsburgh, Pennsylvania, 1911, d. Pasadena, California, March 14, 1995], and Fred Hoyle demonstrate that a “hot big bang” correctly predicts the amounts of deuterium and lithium that are observed in the universe. *See also* 1948 AST; 1967 AST.

Brandon Carter coins the term “anthropic principle,” which states that we observe a universe that is observable because it allows us (humans) to develop. Many other universes (nonobservable) may exist. This idea will be much debated in ensuing years.

Mariner 10 discovers the mag-



Stephen William Hawking
[b. Oxford, England, January 8, 1942]

In 1974 Hawking calculated that black holes emit a form of energy now known as Hawking radiation. Since then he has analyzed the shape and fate of the universe in technical studies and popular books. Although Hawking has been afflicted with severe progressive muscle degeneration since the early 1960s, he manages with the use of a speech synthesizer to continue as Lucasian professor of mathematics at Cambridge University (since 1979), the chair once held by Isaac Newton.

netic field of Mercury. *See also* 1973 AST.

On February 12 Soviet space probe *Mars 5* (launched July 25, 1973) orbits Mars. On August 5 *Mars 6* (launched August 5, 1973) flies by and ejects a capsule that crashes on Mars. *Mars 7*, launched on August 9, 1973, as it flies by launches a capsule that misses Mars entirely. *See also* 1975 AST.

■ Biology

Genetic engineering, in which the genes of one organism are inserted in another, is viewed with alarm by a committee of 139 scientists from the U.S. National Academy of Sciences, led by Paul Berg, which in July calls for a halt in specified research until the implications are better understood. *See also* 1973 BIO; 1976 BIO.

Monoclonal antibodies and fluorescence are used to reveal the structure of the “skeleton” of a cell, or cytoskeleton. The experiment demonstrates that cytoplasm is filled with microtubules that give the cell its structure.

Lars Terenius [b. Örebro, Sweden, July 9, 1940] and Agneta Wahlstrom discover that certain small peptides naturally produced in the body act upon the opiate receptors in the brain. *See also* 1975 BIO.

Alan E. Jacob and Robert W. Hedges discover transposons, genetic elements in bacteria

(later discovered in other organisms) that can move from one plasmid to another easily or that can move from the chromosome to a plasmid or to another chromosome. *See also* 1950 BIO.

Gary K. Beauchamp, Kunio Yamazaki, and Edward A. Boyse observe that mice are able to distinguish other mice that have the same genes for the major histocompatibility complex, a part of the immune system that identifies “self” as opposed to “nonself.” Later it will be determined that mice accomplish this by the sense of smell.

Albert Claude and George Palade of the United States and Belgian cytologist Christian René de Duve share the Nobel Prize for physiology or medicine for the advancement of cell biology, electron microscopy, and structural knowledge of cells. *See also* 1945 BIO; 1956 BIO; 1949 BIO.

□ Chemistry

Scientists in the United States and Russia create element 106, later named seaborgium (Sb).

Aaron Klug [b. Zelvas, Lithuania, 1926] and coworkers determine the crystal structure of transfer RNA. *See also* 1982 CHEM.

Paul J. Flory wins the Nobel Prize in chemistry for his study of long-chain molecules. *See also* 1948 CHEM.

↳ Communication

Noticing a need for book-marks that could not slip out but that could be easily removed when necessary, 3-M engineer Art Fry begins to develop what would become familiar, by the mid-1980s, as Post-It Notes, slips of paper with a glue just strong enough but not too strong.

Historian Arno Peters [b. Berlin, May 22, 1916, d. Bremen, Germany, December 2, 2002] develops a type of map projection that respects the proportions of the sizes of countries near the North and South Poles to a larger degree than his predecessors Van der Grinten and Mercator. *See also* 1904 COMM; 1988 COMM.

The United Nations sets the first international fax standard (the Group 1), which allows facsimile messages to be transmitted at about one page in six minutes. *See also* 1913 COMM; 1980 COMM.

▀ Computers

Hewlett-Packard introduces the programmable pocket calculator. *See also* 1971 COMP.

A computer memory chip (DRAM) with 4 kilobits (4096 bits) of memory becomes commercially available; it will be used in the first U.S. personal computers. *See also* 1970 COMP; 1976 COMP.

Genetic engineering

Genetic engineering consists of a set of methods to change the genes of an organism so that proteins produced by that organism differ in type or quantity from those produced by a “wild” organism — one that has not been altered. Although people have been causing such changes in organisms since domestication began about 10,000 years ago, the phrase *genetic engineering* conventionally refers to a set of techniques that became possible only in 1973.

It is easy to think that genetic engineering was the inevitable outcome of the Watson-Crick explanation of the mechanism of heredity in 1953, but that is not really the case. While knowledge of DNA structure and the genetic code is essential to genetic engineering, the path that led to practical results was separate from the path that led to understanding. Along the way, of course, both paths interacted constantly. The path that led to practical applications could not have been predicted in advance, as almost all of the important discoveries were previously unsuspected by any scientist.

The start of the path toward genetic engineering occurred in 1952 when Joshua Lederberg discovered that bacteria, like some protists, conjugate to exchange genetic material. This behavior, much like sex in multicellular organisms, led Lederberg to perceive that there are two populations of bacteria, which he called M and F. The F population contains a body that he called a *plasmid*. After conjugation, the F bacterium passes the plasmid on to the M bacterium, with which it has conjugated. (It would appear that Lederberg had his sexes backward, but that is not essential to what follows.) This discovery was completely surprising.

The next year William Hayes established that the plasmid consists of genetic material. By then it was clear that genes are DNA; therefore, plasmids are rings of DNA floating free of the main DNA of a bacterium.

About the same time, an apparently unrelated situation became a major problem. Both the sulfa drugs and the antibiotics of the late 1930s and 1940s were, in the 1950s, beginning not to work as well as they had. Many bacteria were becoming resistant to those drugs. Epidemics, especially in hospitals, could no longer be controlled. Many scientists studied the problem. In 1959 Japanese scientists discovered that the genes for drug resistance were carried on plasmids, and therefore passed from bacterium to bacterium. Within a given bacterium, the plasmids multiplied, so there were plenty of copies to pass around. Inserting a few drug-resistant bacteria into a colony of bacteria that showed no resistance resulted in short order in a colony that was completely resistant.

It is not surprising that some bacteria had plasmids that protected against these drugs. Antibiotics are natural substances found in the environment, so some bacteria have evolved defenses against them. The increase in the amount of antibiotics caused by human intervention led to the resistant bacteria passing the plasmids around to larger populations.

In the meantime, another line of research was also leading toward genetic engineering. Starting right after World War II, a number of biologists made an intensive study of viruses that infect bacteria, which are collectively called bacteriophages, or just phages. This line of research demonstrated that genes are part of DNA and not part of a protein, as had previously been suspected. As early as 1946 Max Delbrück and Alfred Hershey independently showed that the genes from different phages could spontaneously combine. Werner Arber studied the mutation process in phages in detail. In the process he discovered that bacteria resist phages by splitting the phage DNA with enzymes. Subsequent recombination of split genes was a consequence of this. By 1968 Arber had located the enzymes that split DNA at specific locations. The split ends are “sticky”; that is, different genes that have been split at the same location by one of these restriction enzymes, as they came to be called, will recombine when placed together in the absence of the enzyme. The resulting product is called recombinant DNA.

The following year, 1969, Jonathan Beckwith and coworkers became the first to isolate a single gene. It was a bacterial gene for a part of the metabolism of sugar.

In 1973 Stanley Cohen and Herbert Boyer combined the restriction enzymes with plasmids with isolation of specific genes to introduce genetic engineering. They cut a chunk out of a plasmid found in the bacterium *Escherichia coli* and inserted into the opening a gene from a different bacterium. Then they put the plasmid back into the bacteria *E. coli*, where copies were made and transferred to other bacteria. Within months other scientists repeated the trick, inserting genes from fruit flies and frogs into *E. coli*.

Not all scientists thought this was a good thing. In July 1974, Paul Berg and other biologists met under the auspices of the U.S. National Academy of Sciences to draw up guidelines that would prohibit certain kinds of genetic engineering.

Since 1974, the tension between those who are rapidly advancing genetic engineering and those who worry about where it is going has continued. By the 1980s, the genetic engineers were producing useful products from bacteria and yeasts, including human growth hormone, human insulin, and a vaccine for hepatitis B. All these are made in tanks in controlled environments and have ceased to evoke much resistance from scientists or the public. There has been more resistance to experiments in which genetically engineered bacteria are released in the environment, although a number of small-scale releases have so far not resulted in known environmental damage. Another source of concern relates to the safety of the many farm crops that have been modified by genetic engineering.

In one area, the progress of genetic engineering has been frustratingly slow. From the beginning of the new technique, there has been hope that it could be used to cure human genetic diseases. So far, that has not proved practical in most cases, although there has been some limited success.

In July Jonathan Titus describes in *Radio Electronics* how to build the MARK-8 "Personal Minicomputer"; it uses the Intel 8008 microprocessor and is the precursor of the Altair 8800. *See also* 1972 ELEC; 1975 COMP.

The first championship for computer chess is held in Stockholm. *See also* 1958 COMP; 1982 COMP.

David Ahl develops a micro-computer consisting of a video display, keyboard, and CPU. Ahl's employer, DEC, shows no interest. *See also* 1958 COMP; 1975 COMP.

Construction

The CN Tower in Toronto, Ontario, becomes the tallest *structure* in the world, surpassing the Sears Tower in Chicago, Illinois, although the Sears Tower continues as the world's tallest *building*, since the CN Tower is essentially a radio and television transmitting tower. The CN Tower reaches a height of 550 m (1805 ft). *See also* 1973 CONS.

Ecology & the environment

(Frank) Sherwood Rowland [b. Delaware, Ohio, June 28, 1927] and Mario Molina [b. Mexico City, March 19, 1943] warn that chlorofluorocarbons (also called Freons), commonly used as spray propellants and in refrigeration, may be destroying the ozone layer in the atmosphere. The ozone layer protects against excessive ultraviolet radiation; such radiation can cause skin cancer. *See also* 1931 MATR; 1976 MATR.

Scientists report that acid rain transcends borders, as coal-burning electric utilities in the

U.S. Midwest are blamed for high acidity in lakes of the northeastern United States and eastern Canada. *See also* 1961 ECOL.

Brazil starts a major program to replace part of gasoline fuel in automobiles with ethyl alcohol, a mixture called gasohol. Unlike gasoline, based on non-renewable petroleum, ethyl alcohol can be produced from plants such as maize (corn). By 1980 there are 750,000 automobiles running on gasohol in Brazil. *See also* 1860 ENER.

Electronics

French journalist Roland Moreno invents the memory card or "smart card." It is a type of credit card in which information is stored on a tiny chip instead of on a magnetic track.

T. Peter Brody and coworkers at Westinghouse show that thin-film transistors can be used effectively to control liquid-crystal displays. *See also* 1962 ELEC; 1984 COMM.

In April Intel develops the 8080 chip, which at 2 MHz is ten times as fast as the 8008. Motorola introduces the 6800 chip.

Mathematics

Theodore P. Baker, John Gill, and Robert M. Solovay show that two classes of propositions exist in which propositions are equivalent based on one set of postulates and not equivalent based on another set of postulates, even if each postulate set is internally consistent.

Pierre René Deligne [b. Brussels, Belgium, October 3, 1944] resolves three of André Weil's conjectures using algebraic geometry. *See also* 1949 MATH.

Roger Penrose [b. Colchester, England, August 8, 1931] dis-

covers a way to tile a plane using two different rhombuses so that the ratio of fat rhombuses to thin ones is an irrational number, specifically the golden mean. Such a Penrose tiling has no cell that contains an integral number of rhombuses. *See also* 1984 MATR.

Medicine & health

Michael Phelps [b. Cleveland, Ohio, 1939], Ed Hoffman, and Michael Ter-Pogossian develop a forerunner of the PET scanner, a tomographic device that images positron emitting radionuclides. *See also* 1951 MED.

Stanley Milgram [b. New York City, 1933, d. December 20, 1984] describes in *Obedience to Authority* experiments that show that people tend to obey authority figures, even if ordered to punish innocent people.

Physics

American John Schwarz [b. c. 1940] and French physicist Joel Scherk [b. 1947, d. 1980] (and independently in Japan Tamiaki Yoneya) find a link between string theory and gravity, and suggest that gravitational force is carried by particles called gravitons. They also propose that string theories describe all fundamental subatomic particles. In this same year, Schwarz indicates that the universe has ten dimensions instead of the four commonly recognized (length, height, width, and time) or the 26 proposed in some earlier precursors of string theory. *See also* 1984 PHY.

Howard M. Georgi [b. San Bernardino, California, January 6, 1947] and Sheldon Glashow develop the first of the grand unified theories (or GUTs) that account for the

strong, weak, and electromagnetic forces as variants of a single force that is broken into parts when the universe begins to cool down after the big bang. *See also* 1967 PHY.

Independently, Burton Richter [b. New York City, March 22, 1931] and Samuel Chao Chung Ting [b. Ann Arbor, Michigan, January 27, 1936] discover a new subatomic particle which Richter calls the psi particle and Ting calls the J particle; it is important in that it tends to confirm the charm theory. Today the particle is called the J/psi. *See also* 1964 PHY; 1976 PHY.

Anthony Hewish and Martin Ryle of England win the Nobel Prize in physics, Hewish for his discovery of pulsars and Ryle for his improvements in radiotelescopy. *See* 1967 AST; 1960 AST.

Tools

Electronic scanners that use a laser to read bar codes on merchandise for price and to report on inventory are first introduced at the Marsh Supermarket in Troy, Ohio, on June 24, followed by several other US supermarkets; the first purchase is a 10-pack of chewing gum. In 1980 there is a general introduction of the technique. *See also* 1960 COMM.

Optical pulses less than a trillionth of a second long are produced by lasers at Bell Labs.

Transportation

On July 3 cosmonauts Pavel Popovich and Yuri P. Artukhin are launched on the *Soyuz 14* mission; they occupy the *Salyut 3* space station and study Earth resources. Cosmonauts Gennady Sarafanov and Lev Demin begin a two-

Strings to branes

When people first began thinking about quarks, a persistent question was why isolated quarks had not been observed. One idea was that quarks might be the ends of strings. If a particle was a string and the quarks were just the ends of the string, then it could be understood why one never found one quark without another. This idea did not gain much acceptance, but strings soon took on a life of their own.

A string is essentially a one-dimensional object in a space of four dimensions (counting time as a dimension). Physicists in 1970 turned to topology, the mathematics of knots and surfaces, to find what the implications might be of using strings instead of particles in their calculations. Surprisingly, strings simplified calculations. But some string theories had far too many dimensions — 26 in one version.

At about the same time, physicists working with other mathematical theories of particles and forces rediscovered an idea from the 1920s. In 1919 Theodor Kaluza had found a way to derive electromagnetism from Einstein's theory of general relativity, but Kaluza's derivation requires five dimensions and we only observe four. In 1926 Oskar Klein developed an explanation of why the fifth dimension is invisible — it curls up into a tiny circle — but very few people were impressed.

In the late 1970s, however, string theorists discovered that their theories became very simple if the universe has eleven dimensions with seven of them curled up in the way Klein suggested. Now physicists tried putting strings into spaces with more dimensions. The complicated mathematics of strings showed that they work best in Kaluza-Klein spaces of nine or ten dimensions, not eleven. Happily several physicists showed

that spaces of ten dimensions could be transformed into spaces of eleven dimensions.

In 1974 the discovery that string theory could explain gravity in a way that reconciles with quantum theory caused many physicists to begin to study the new theory. The key realization here was that a string with a spin of 2 has a mass of 0, which is the same combination as that predicted for the graviton. Two years later gravity was reworked in terms of supersymmetry, a general type of theory that predicts that every fermion has a bosonic "superpartner," and vice versa. The combination of supersymmetry with gravity became known as supergravity. By 1980 physicists also incorporated supersymmetry into string theory, resulting in superstring theory.

But the whole edifice was in trouble. For one thing, none of the effects predicted by superstring theory could be tested at energy levels accessible in even the biggest accelerators. Furthermore, all superstring predictions of effects in the early universe could also be explained by simpler theories. Worse, various mathematical results were clearly impossible. But in 1984, just as in the much older theory of quantum electrodynamics, it was shown that the mathematical anomalies cancelled each other out if handled properly. By then, five different string theories existed and, while consistent within themselves, they were inconsistent with each other.

At this point M theory or brane theory came to the rescue by picturing strings as the intersection of manifolds (M) in eleven-dimension space (which is an outgrowth of ten-dimension space). These manifolds correspond to membranes (M-branes) in four-space. Now all five string theories could be seen as different aspects of the same theory. Furthermore, brane theory showed a striking success in explaining aspects of black holes. So far, however, brane theory cannot be tested experimentally. Also, theoreticians have begun to devise new versions, such as D-brane theory.

day *Soyuz 15* mission on August 26; an attempt to dock with *Salyut 3* is unsuccessful.

On December 2 cosmonauts Anatoly V. Filipchenko and Nikolai N. Rukavishnikov begin the *Soyuz 16* mission to check modifications in the *Salyut* system. On December 10 *Helios*, the first German space probe, is launched.

The U.S. Transportation Department changes its order for air bags for all new U.S. cars from 1974 to the 1977 model year. General Motors begins to offer a few models equipped with air bags, but

drops the program after a couple of years due to poor sales. *See also* 1957 TRAN; 1985 TRAN.

1975

► Anthropology

Donald Johanson and coworkers discover in Ethiopia a group of fossils of *Australopithecus afarensis*, which they nickname the First Family. *See also* 1974 ANTH.

★ Astronomy

Alan E.E. Rogers rediscovers the forgotten idea of Roger C. Jennison for improving the

resolution of radiotelescopes by very-long-baseline interferometry. This time the idea is applied within a year with great success, obtaining a resolution of 0.01 arc-second. *See also* 1953 AST; 1980 AST.

Vera Cooper Rubin [b. Philadelphia, July 23, 1928] and W. Kent Ford discover that the Milky Way Galaxy has a proper motion of about 500 km (300 mi) per second by measuring its speed with respect to a reference frame of distant galaxies.

Groups at Princeton, Berkeley, and Florence about this time

detect the first tiny deviation from isotropy in the microwave background radiation. Termed "dipole anisotropy," the microwave sky appears slightly hotter in the direction of the motion of the galaxy by one part in a thousand. *See also* 1964 AST.

William Hartmann and Donald Davis of Planetary Science Institute, as well as Alfred Cameron and William Ward of Harvard-Smithsonian Center, publish theories, later commonly accepted, that the Moon was formed by a huge impact into Earth early in Earth's history.

Charge-coupled devices (CCDs), invented in the 1960s at Bell Labs, are installed in astronomical telescopes for the first time by NASA's Jet Propulsion Laboratory and the University of Arizona in the United States. *See also* 1974 AST.

On June 8 The Soviet Union (Russia) launches *Venera 9*; its twin *Venera 10* is launched on June 14. *Venera 9* makes the first soft landing on another planet and then returns the first photographs from the surface of Venus, continuing in operation for 53 minutes before the great heat of 485°C (905°F) and 90-bar pressure cause it to malfunction. *Venera 10* lands on Venus on October 25 and returns images for 65 minutes. *See also* 1962 AST; 1982 AST.

On August 20 the United States launches *Viking 1*, which will become the first U.S. space probe to soft-land on Mars; it continues to return data until May 1983. On September 20 the United States launches *Viking 2*, which also will successfully land on Mars. *See also* 1976 AST.

Biology

Geneticists meeting in Asilomar in California decide for a moratorium in recombinant DNA research. *See also* 1974 BIO.

In Scotland John Hughes and Hans Kosterlitz, independently of Lars Terenius and Agneta Wahlstrom, discover enkephalin, a peptide that acts on the opiate receptors in the brain, producing effects similar to those of morphine. The enkephalins are the first pain-relieving neurotransmitters to be found. *See also* 1974 BIO; 1977 BIO.

Edward Wilson introduces the concept of sociobiology,

which he defines as "the systematic study of the biological basis of all social behavior." *See also* 1964 BIO.

David Baltimore and Howard Temin of the United States and Italian-American virologist Renato Dulbecco win the Nobel Prize for physiology or medicine, Baltimore and Temin for their discovery of reverse transcriptase and Dulbecco for his discovery of the interaction between viruses and host cells. *See also* 1974 BIO; 1958 MED.

Chemistry

John Warcup Cornforth and Yugoslav-Swiss chemist Vladimir Prelog win the Nobel Prize in chemistry, Cornforth for his work on the structure of enzyme-substrate combinations and Prelog for his study of asymmetric compounds. *See also* 1951 CHEM; 1956 CHEM.

Communication

IBM introduces the first high-speed laser printer, the 3800, which creates an output comparable to that obtained by photocomposition. *See also* 1971 COMM; 1976 COMM.

Xerox files for a patent on Ethernet, an access protocol for local area networks that have a ring structure; each packet of data carries an address allowing the system to direct it to its destination. *See also* 1973 COMM.

Threshold Technology develops a computer, based on a system developed by Thomas B. Martins and R.B. Cox, that can understand spoken commands and that replies with a synthetic voice. *See also* 1978 COMM.

Paul Gardner Allen [b. 1953]

and William Henry Gates III [b. Seattle, Washington, October 28, 1955] write a BASIC compiler for the Altair 8800. *See also* 1977 COMP.

Computers

H. Edward Roberts introduces the first successful personal computer, the Altair 8800, in kit form in the United States. It has 256 bytes of memory and programs or data must be entered with toggle switches in binary numbers. The output is a display of lights in the front panel that also represents binary numbers. *See also* 1974 COMP; 1977 COMP.

IBM designs a microcomputer with code name 5100; it is not distributed because of the belief that there will be no market for microcomputers. *See also* 1974 COMP; 1981 COMP.

John Cocke and coworkers at IBM begin the 801 project, the development of a minicomputer that employs what later comes to be known as RISC architecture. *See also* 1971 COMP; 1988 COMP.

Because of antitrust legislation, ITT makes the UNIX operating system available to universities, where it undergoes further development. *See also* 1991 COMP.

Food & agriculture

The McDonald's fast-food chain replaces the cardboard foil-and-paper wrapping for a Big Mac hamburger with a one-piece polystyrene "clamshell." *See also* 1988 FOOD.

Mathematics

Mitchell Jay Feigenbaum [b. Philadelphia, December 19, 1944] discovers Feigenbaum's number, which is represented by a lower-case sigma (σ) and is

approximately 4.669201609103. It is the ratio toward which the consecutive differences of almost any iterated functions tends.

Medicine & health

César Milstein [b. Bahia Blanca, Argentina, October 8, 1927, d. Cambridge, England, March 24, 2002] and Georges J.F. Köhler [b. Munich, Germany, April 17, 1946, d. Freiburg im Breisgau, Germany, March 1, 1995] announce in the United Kingdom their discovery of how to produce a single line of identical antibodies, which are termed monoclonal antibodies. *See also* 1984 MED.

Physics

A method of cooling particles called "optical molasses" is proposed; the particle would be placed in the intersection of three laser beams, each designed to resist any motion an atom makes in the direction of that beam. *See also* 1933 MATR; 1985 TOOL.

Abraham Pais and Sam Treiman [b. Chicago, Illinois, May 27, 1925, d. New York City, November 30, 1999] coin the term "standard model" to describe the description of particle physics that now includes the electroweak theory and four quarks. Later, two more quarks will be added along with other ideas, but the term for the overall theory will stick. *See also* 1977 PHY.

James Rainwater of the United States and Ben Mottelson and Aage Bohr of Denmark win the Nobel Prize in physics for their studies proving the asymmetrical structure of the atomic nucleus. *See also* 1949 PHY; 1951 PHY.

Monoclonal antibodies

The human immune system is complex, but one of the most easily accessible parts is a group of chemicals called antibodies that circulate in the bloodstream. Antibodies are the key to the success of vaccination. Injection of a vaccine stimulates a kind of white blood cell (lymphocyte) called a B cell to produce antibodies against proteins in the vaccine. Such antibodies home in on specific foreign proteins so that they can be destroyed. Vaccination confers long-lasting immunity because the B cells that have been stimulated to produce the antibodies reproduce, and the B-cell line remains in the bloodstream, prepared to produce antibodies against a reinvasion of the specific protein. The same process, of course, happens naturally in response to infection.

The key to antibody action is that a line of antibodies that bind to one kind of protein or other molecule — called the antigen — is very specific. Normally, antibodies in a given line do not bind to any molecules except that antigen, although sometimes antibodies can be fooled by a protein that closely resembles the antigen in some way; this can result in autoimmune diseases such as type I diabetes or rheumatoid arthritis.

In 1975 César Milstein and Georges Köhler developed in England a method of producing large amounts of antibodies specific to a given antigen by a cloning technique. Antigens from human cells are injected into a mouse. Some B cells in the mouse start producing antibodies that attack the antigen. B cells are then removed from the mouse and fused with cancerous mouse B

cells, forming hybrid cells called hybridomas that live and reproduce indefinitely. (B cells alone soon die out.) The hybridomas continue to produce large amounts of antibodies of various types. Probes based on the original antigen are used to pick out a hybridoma that produces a specific desired antibody; this cell is separated from the others and encouraged to reproduce in large quantities. Antibodies from such a cell line are called monoclonal because they are produced from the clones of a single hybridoma. All of the monoclonal antibodies from a single B cell react with the chosen antigen.

The original mouse-produced antibodies sometimes caused undesired immune reactions when injected into a human. The problem is that human immune systems view mouse proteins as foreign. More recently, scientists have used human cells to make the hybridomas, reducing such unwanted reactions when monoclonal antibodies are injected into humans.

Just like natural antibodies, monoclonal antibodies track down proteins or other chemicals with exquisite specificity. Thus, they can be used in diagnosis of such diseases as muscular dystrophy, one of the first applications. By combining a monoclonal antibody with a poison, cells that have a given protein on their surface can be tracked down by the antibody and destroyed. This has been successful against some types of cancer, especially certain breast cancers and leukemias. Antibodies are also used to prevent organ rejection and to inhibit clogging of arteries. Although the concepts involved date from the mid-1970s, practical applications were slow to develop. But by the early 21st century, several drugs based on monoclonal antibodies had become routinely used.

→ Transportation

Soviet cosmonauts Alexei A. Gubarev and Georgi M. Grechko begin the *Soyuz 17* mission on January 10; the craft docks with *Salyut 4* and sets the Soviet endurance record at 30 days. Cosmonauts Vasily G. Lazarev and Oleg G. Makarov are launched on April 5 on the *Soyuz 18A* mission, which ends after 22 minutes because a separation from a booster fails and the craft does not reach orbit; however, the crew lands successfully in western Siberia. Pytor I. Klimuk and Vitaly I. Sevastyanov begin the 63-day *Soyuz 18B* mission on May 24; the craft docks with *Salyut 4*. On November 17 the Soviets launch a *Soyuz 20* biological mission with no crew; the craft docks with *Salyut 4*.

The first cooperative U.S.-Soviet space mission, the Apollo-Soyuz Test Project, is launched on July 15; a three-man Apollo spacecraft docks with the two-man Soviet *Soyuz 19*. The American crew in the Apollo consists of Thomas P. Stafford, Vance D. Brand, and Donald K. Slayton. In the *Soyuz 19* are cosmonauts Alexei A. Leonov and Valery N. Kubasov.

1976

◀ Anthropology

Mary Leakey and coworkers discover the 3,000,000 year-old footprints made by three members of *Australopithecus afarensis* in volcanic tuff at Laetoli, Tanzania. The

hominid trail is found among thousands of animal footprints left in ash when a nearby volcano erupted. See also 1975 ANTH; 1979 ANTH.

★ Astronomy

Thomas Kibble of Imperial College in London theorizes that as the universe cooled after the big bang, various flaws that would arise would form cosmic strings, long, very thin, bundles of the original energy of the universe that would persist even today. The cosmic strings would have great mass-energy, so that 1.6 km (1 mi) of length of one of the proton-wide strings would have about the same mass as Earth. (Note that these are not related to the strings of superstring theory.) See also 1985 AST.

Astronomers discover that Pluto is at least partially covered with frozen methane. See also 1988 AST.

U.S. space probes *Viking 1* and *Viking 2* soft-land on Mars and begin sending back direct pictures and other information from the surface of the planet. *Viking 1* on June 19 is the first spacecraft ever to begin an extended report from a planet other than Earth. See also 1975 AST.

◀ Biology

Expert committees in the United States and the United Kingdom introduce guidelines for genetic engineering research, imposing safe laboratory practices; many other countries subsequently introduce similar

guidelines. *See also* 1974 BIO; 1978 MED.

Genentech, the first commercial company devoted to the development of products through genetic engineering, is established in South San Francisco, California. *See also* 1974 BIO; 1980 BIO.

Susumu Tonegawa [b. Nagoya, Japan, September 6, 1939] reports his experiment showing that the genes responsible for producing antibodies move physically close together on a chromosome and produce the large variety of antibodies by combination. *See also* 1987 MED.

Martin F. Gellert and coworkers discover the enzyme gyrase that causes DNA to form supercoils, the natural state of most DNA in the cell. Although DNA is naturally coiled into a double helix, that helix is further coiled to form a larger helix called a supercoil.

Har Gobind Khorana and coworkers announce construction of a functional synthetic gene, complete with regulatory mechanisms.

Erwin Neher [b. Landsberg, Germany, March 20, 1944] and Bert Sakmann [b. Stuttgart, Germany, June 12, 1942] develop the patch-clamping technique to study the traffic of ions across cell membranes. By tightly sealing a very thin glass pipette against a cell membrane one can isolate a small patch of it and study the ion channels it contains. *See also* 1991 BIO.

Chemistry

Soviet scientists at Dubna create element 107, bohrium (Bh), by striking chromium with bismuth.

William N. Lipscomb wins the

Nobel Prize in chemistry for his study of bonding in boranes. *See also* 1963 CHEM.

Communication

IBM develops the ink-jet printer. *See also* 1975 COMM; 1978 COMM.

Threshold Technology introduces a voice recognition unit, the Threshold 600; it can recognize up to 100 words 300 milliseconds after hearing them; the processing time is one second when the full 512-word vocabulary is used. *See also* 1975 COMM; 1978 COMM.

JVC introduces the VHS (video home system) format for videotape. *See also* 1971 COMM; 1989 COMM.

Michael Shrayer creates Electric Pencil, the first word-processing system for a personal computer, for the Altair 8800. *See also* 1972 COMM; 1978 COMM.

Computers

Stephen Wozniak [b. Sunnyvale, California, 1950] designs the Apple I computer based on Motorola's 6052 processor. It addresses 4K of random access memory (RAM) in the least expensive version. Programs in BASIC or data can be entered with a keyboard or a cassette tape, and the output can be displayed on a television screen. The keyboard, power supply, and cassette system are all sold separately. About 175 Apple I's are sold. *See also* 1976 ELC; 1977 COMP.

Gary Kildall [b. 1942, d. Monterey, California, July 1994] develops CP/M (Control Program for Microcomputers), an operating system widely used in 8-bit personal computers during the late 1970s and early 1980s. *See also* 1981 COMP.

Seymour Cray of Cray Research completes the Cray-I, the first supercomputer with a vectorial architecture. In order to shorten connections between components, he designs the computer in a cylindrical form. *See also* 1971 COMP; 1982 COMP.

In May IBM introduces its first microcomputer, the 5100, with 16 K of memory.

Ecology & the environment

The Givaudan-La Roche Icmesa pesticide plant near Seveso, Italy, accidentally releases a cloud of poisonous gas that spreads dioxins over 730 h (1800 a), killing dogs and farm animals, but causing no human fatalities (except the spontaneous abortion of fetuses.). Local people are temporarily evacuated from the region. *See also* 1988 ECOL.

The U.S. National Academy of Sciences reports that Freon used in various spray cans can deplete the ozone layer in the atmosphere, resulting in increased ultraviolet radiation at the surface level of Earth. *See also* 1974 ECOL; 1978 ECOL.

The U.S. General Services Administration opens an environmental demonstration building in Saginaw, Michigan, in October; in addition to a solar collector in the roof for heating and cooling and doubled-glazed windows with overhanging roofs, the building features large masses of soil, called earth berms, piled against walls to reduce heat loss. *See also* 1948 ENER.

Electronics

Zilog develops the 8-bit Z80 microprocessor that can

address 64 K of memory and has a clock speed of 2.5 MHz (increased to 8 MHz in 1983); it becomes widely applied in 8-bit computers. *See also* 1974 COMP; 1981 ELEC.

Chuck Peddle develops the 6502 microprocessor, which uses MOS technology. The 6502 is used in the Apple I computer (because it is about a seventh the cost of Intel's 8080). *See also* 1977 COMP.

Materials

The very hard metal called Coromant is introduced; it allows very rapid tooling of metal parts. *See also* 1898 MATR.

On November 23 Hideki Shirakawa adds bromine to a preparation of polyacetylene, which greatly increases the electrical conductivity of the plastic. *See also* 1967 MATR; 1977 MATR.

The U.S. Congress passes the Toxic Substances Control Act, intended to keep dangerous chemicals out of the environment. *See also* 1957 ECOL.

Mathematics

Kenneth Appel [b. Brooklyn, New York, November 8, 1932] and Wolfgang Haken [b. Berlin, June 21, 1928] show by investigating 2000 individual cases by computer that four colors are sufficient to color any planar map in such a way that no two regions of the same color border each other (that is, touch at more than a single point).

Medicine & health

Harold Varmus and J. Michael Bishop [b. York, Pennsylvania, February 22, 1936] discover genes in normal cells that can cause cancer, which they name oncogenes. *See also* 1989 MED.



Harold Elliot Varmus

[b. Oceanside, New York, December 18, 1939]

Varmus and J. Michael Bishop discovered that the genes that control cell growth and division can change into abnormal forms that trigger endless cell division — a hallmark of cancer. Varmus also is widely recognized for his studies of the replication cycles of retroviruses and hepatitis B viruses, the functions of genes implicated in cancer, and the development of mouse models for human cancer. In 1993 Varmus became the first Nobel laureate to be appointed director of the National Institutes of Health (NIH).

One of the best known cancer-causing genes, the *src* gene that causes cancer in chickens as a result of infection by a virus, the Rous sarcoma virus, is found to be a normal chicken gene that has been somehow picked up by the virus and changed to a cancer-causing gene. *See also* 1910 MED.

Some 200 people attending the 1976 American Legion Convention become infected by the Legionella bacterium, which causes a newly recognized form of pneumonia — Legionnaires' disease.

Baruch Blumberg and D. Carleton Gajdusek of the United States win the Nobel Prize for physiology or medicine for their identification of the hepatitis antigen and slow viruses. *See also* 1964 MED; 1966 MED.

* Physics

Burton Richter and Samuel Ting of the United States win the Nobel Prize in physics for the parallel discovery of the subatomic particle that establishes the existence of charm. *See also* 1974 PHY.

I Tools

American physicist John M.J. Madey builds a free-electron laser (FEL). The photons are amplified in a beam of free electrons generated by an accelerator that passes through an alternating magnetic field.

Each time the electrons are deflected by the field they emit photons, which in turn stimulate the emission of new photons by the electrons. *See also* 1970 TOOL; 1980 TOOL.

→ Transportation

Soviet cosmonauts Boris V. Volynov and Vitaly Zholobov begin the *Soyuz 21* mission on July 6; the craft docks with *Salyut 5* and the crew performs Earth resource work. Valery F. Bykovsky and Vladimir Aksenenko are launched on September 15 on the *Soyuz 22* mission, during which they take Earth resource photographs. Vyacheslav Zudov and Valery Roshdestvensky begin the *Soyuz 23* mission on October 14; attempts to dock with *Salyut 5* are unsuccessful.

The French-British supersonic transport, the Concorde, goes into regular service across the Atlantic. Carrying at most 100 passengers, the Concorde fails to become economically successful even with high fares. It is maintained in service largely as a matter of prestige for the French and British governments. *See also* 1969 TRAN; 2003 TRAN.

1977

▲ Archaeology

Greek archaeologist Manolis Andronicos [b. October 23,

1919, d. 1992] discovers at Vergina in Macedonia what most authorities consider to be the tomb of King Philip II, father of Alexander the Great.

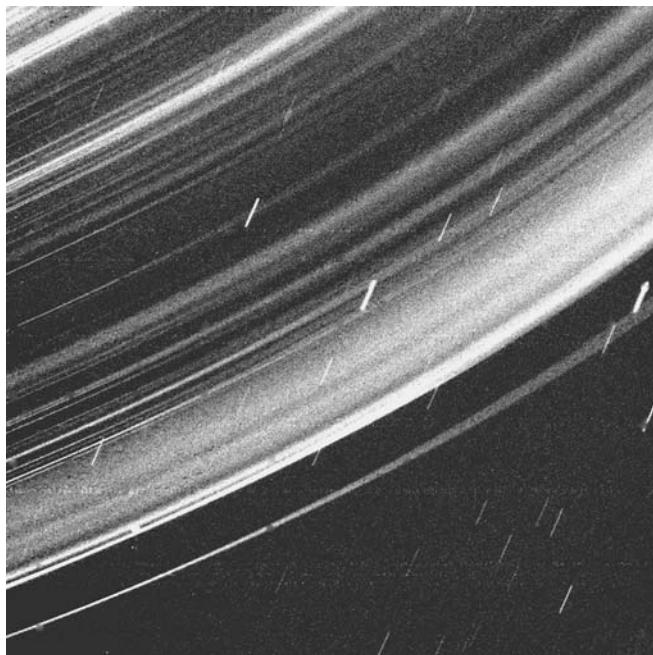
★ Astronomy

The Vela pulsar, thought to be 800 light-years from Earth and to have formed some 11,000 years ago, is identified with a visible star by astrono-

mers at Siding Spring, Australia. It is the second pulsar for which the optical counterpart is known. *See also* 1968 AST.

Charles Kowal discovers Chiron, a large body in the outer solar system that will come to be thought of as a comet that is not near enough the Sun to develop a tail. *See also* 2001 AST.

On March 10 James L. Elliot, Edward Dunham, and Douglas Mink aboard NASA's Kuiper airborne observatory discover the rings of Uranus during an occultation of a star by the planet. R. L. Millis, P. Birch, and D. Trout at the Perth Observatory in Australia also observe the rings. *See also* 1984 AST.



RINGS OF URANUS The rings are usually seen from a greater distance as a single narrow band. This close-up Voyager 2 image of Uranus's rings from only 236,000 km (142,000 mi) and from within the shadow cast by the planet reveals fine dust lanes between more than a dozen sharply defined rings that consist of larger pieces of rock or ice.

A team led by George Smoot [b. Yukon, Florida, February 20, 1945] discovers temperature variations in the background radiation. This anisotropy is viewed as the seed structures for the formation of galaxies. *See also* 1992 AST.

On February 5 a fireball as bright as the full Moon is observed by an airplane flying over Saskatchewan, Canada. The first piece of the meteorite is located near Innisfree, Alberta, on February 17. In April, after snows melt, eight more pieces are found. The total weight comes to 4.6 kg (10.1 lb). *See also* 1970 AST; 2002 AST.

On August 20 the United States launches *Voyager 2*. After studying Jupiter and Saturn, it becomes the first space probe to reach the vicinities of Uranus and Neptune. *Voyager 1* is launched second, on September 5. After studying Jupiter, it becomes the second space probe to reach the vicinity of Saturn. *See also* 1973 AST; 1980 AST.

Biology

Phillip Allen Sharp [b. Falmouth, Kentucky, June 6, 1944] and, independently, Richard J. Roberts [b. Derby, England, September 6, 1943]

and their coworkers discover that DNA from organisms other than monerans (bacteria and some algae) contains long stretches of meaningless information that is discarded in making proteins. The discarded material is called an intron, while the active gene is an exon. *See also* 1990 BIO.

Carl Woese shows that a third primary group of organisms exists besides eukaryotes (plants, animals, protists, and fungi) and prokaryotes (bacteria and blue-green algae). Named archaea, the group consists of certain one-celled organisms previously classified with bacteria. Genetically they are very different from prokaryotes, however, and can live in extreme physical and chemical environments, such as hot springs.

In Sweden, Tomas G.M. Hökfelt finds that most neurons contain several different neurotransmitters, not just one. *See also* 1975 BIO.

Frederick Sanger and Walter Gilbert independently develop nucleotide sequencing techniques. Sanger and coworkers determine the DNA sequence of a bacteriophage, the first complete genome for a virus (or any other organism). *See also* 1978 BIO.

Chemistry

Russian-Belgian Ilya Prigogine wins the Nobel Prize in chemistry for nonequilibrium theories in thermodynamics. *See also* 1971 PHY.

Communication

General Telephone and Electronics uses optical fiber cables to transmit live telephone calls in the first large-scale trial of fiber optics.

The first linked automatic teller machines (ATMs) are introduced by a Denver-based credit card processor. *See also* 1969 COMM.

Steven Paul Jobs

[b. Los Altos, California, February 24, 1955]

After teaming with Steve Wozniak to build a device to make long-distance calls from pay phones without paying, Jobs and Wozniak created one of the first personal computers and, in 1977, the Apple II, the first home computer in a case with the ability to display color and record data using a disk drive. Jobs's specialty was in directing innovation — seeing what was needed and making it available. This led to computers that included the use of icons and a mouse, neither of which Jobs invented, but which he brought successfully to market.

Computers

In April Steven Paul Jobs and Stephen Wozniak introduce the Apple II, the first personal computer available only as an assembled unit. Capable of displaying color on a television set used as a monitor, the Apple II with eight expansion slots becomes the best-selling personal computer until the introduction of the IBM PC. *See also* 1975 COMP; 1981 COMP.

Paul Allen and William Gates found Microsoft, which in the next years becomes the most important producer of software for microcomputers. *See also* 1981 COMM.

Tandy Corporation and Commodore Business Machines introduce personal computers that have built-in monitors; other available microcomputers rely on separate television sets. Both the Tandy and Commodore computers also come with tape cassettes for data and program storage. *See also* 1960 COMP.

Construction

The Georges Pompidou National Center for Art and Culture opens in Paris on January 31. The building is constructed of concrete slabs enclosed in glass and supported by a network of pipes.



Carl R. Woese

[b. Syracuse, New York, July 15, 1928]

Woese's studies of ribosomal RNA led him to conclude that there are three domains of life: eukaryotes, bacteria, and archaea. He determined that certain one-celled organisms long classified as bacteria — including many species adapted to life in extreme environments such as hot springs and salt ponds — instead form a distinct group in terms of both genetics and chemistry. Initially, Woese's revolutionary conclusions were met with a good deal of skepticism among biologists. But by the mid-1980s, a growing body of supporting evidence led to widespread acceptance of the archaea. In 2002 he challenged the long-standing Darwinian assumption known as the Doctrine of Common Descent — that all life on Earth has descended from a single ancestral organism. Woese proposed that instead of one primordial form, there initially were at least three simple types of loosely constructed cellular organisms swimming in a pool of genes. The types evolved by horizontal gene transfer into the three distinct types of cells.

Robert D. Ballard

[b. Wichita, Kansas, June 30, 1942]

In 1973 and 1974 Ballard participated in the first manned exploration of the underwater mountain range known as the mid-Atlantic ridge. In 1977 he led an expedition in the Galapagos Rift that discovered deep-ocean hydrothermal vents surrounded by dense communities of gigantic tube worms and other exotic creatures. Ballard later helped develop the Argo system, in which a deep-sea sled is pulled along the ocean floor by a ship on the surface. Optical fiber technology is used to transmit video pictures from the sled to the towing ship. Ballard's best-known discovery came in 1985, when he located the wreck of R.M.S. *Titanic*, the ocean liner that sank in 1912 after hitting an iceberg in the North Atlantic. Ballard also located and studied other shipwrecks, including ancient Roman ships along trade routes off the coast of Tunisia in 1997, the first two intact Phoenician ships ever found, and dozens of other ships.

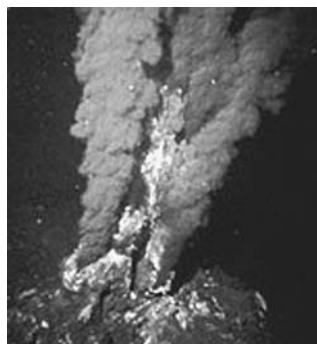
Critics say that it looks more like an oil refinery than an art center.

In June the U.S. air force starts building the world's largest structure made entirely from wood that is glued together, a ramp and platform 38 m (125 ft) high intended for use in testing the effects of electromagnetic pulses (EMP) caused by nuclear explosions. Metal parts are affected by EMP and would interfere with the tests.

Earth science

John B. Corliss [b. 1936], Robert D. Ballard, and Kathleen Crane [b. 1951], aboard the submersible *Alvin*, explore deep-sea ocean rift vents of hot water and sulfur compounds rising from the Galapagos Spreading Center near the Galápagos Islands. Surrounding the hot springs are specialized communities of sulfur-eating bacteria, giant clams, and tube worms. The vents had been recognized in 1976 with remote-controlled water sampling. *See also* 1985 EAR.

A baby mammoth frozen in ice for 40,000 years is recovered in good shape in the Soviet Union (Russia).



DEEP-SEA OCEAN RIFT VENT — A BLACK SMOKER Ocean vents occur most often where two tectonic plates are moving apart, which allows hot magma to flow upward to near the sea floor. Volatile fluids released by the magma travel through cracks in the ocean's bottom carrying very hot minerals that rise through the cold water, producing an effect similar to black smoke from a chimney.

Ecology & the environment

Dutch scientists discover that incinerator wastes are contaminated by dioxins, potentially dangerous chemicals that have been linked to cancer in animal studies. *See also* 1957 ECOL; 1988 ECOL.

The first successful home computer

In the 1950s computers were at first programmed by rewiring them, while later punched cards were used to enter data. By the 1960s some large computers could be programmed and data entered with a typewriter keyboard, but the output was also typescript printed by a modified teletypewriter. The computers were room-sized and the only way anyone could imagine using one at home was by connecting to it with a teletypewriter.

In the early 1970s, however, Intel Corporation began to sell programmable integrated-circuit chips. Several companies took advantage of the new chip to offer kits or even small computers based on it — the first was actually in France in 1973. About this time Steven Jobs teamed up with Steve Wozniak, an electronics wizard. It was Jobs's salesmanship and vision, combined with Wozniak's talent for achieving wonders with very simple circuits, that sparked the personal computer revolution of the 1980s.

They first built the Apple-1 computer, which consisted of a simple board without power supply or case. But there was a demand for it. So they designed the Apple II, a complete product housed in a casing designed by Jobs himself. Technically, the Apple II was far ahead of its competitors. Although it was capable of displaying colors on a TV screen and could store and write with a disk drive, the price was kept low because of the simplicity of the circuits. By 1977 Jobs and Wozniak had sold 4000 Apple IIs, and a year later they could not keep up with the demand. Even after IBM entered the personal computer fray in 1981 and various other companies followed IBM's lead with similar machines ("clones"), the Apple II continued to sell, especially to schools. After several upgrades, the Apple II finally went out of production in November 1993.

One of the secrets of Apple II's success was that every version could access the programs and storage media of the previous version (called "downwardly compatible"). Other early computers, such as the Commodore PET and Atari, failed in this regard, so that if you bought a new computer from the same manufacturer, anything done on the old computer was inaccessible. The IBM PC and its imitators also were downwardly compatible and, furthermore, were compatible with each other. All used operating systems from Microsoft. Ultimately, the ability to transfer material from one computer to another in the Microsoft world worked against Apple II and its principal successor, the Macintosh or "Mac." The Apple computers persistently held on to a share of the market, but their individual operating system, even after Microsoft began to imitate it with Windows, was a barrier between the Apple computers and most of the computer-buying public.

The U.S. government in this year and over the next three years imposes more and more restrictive rules on use of lead shot for hunting migratory birds (mostly ducks and geese) because of the shot causing lead poisoning in wounded birds. By 1980 the ban is complete.

❖ Materials

Researchers from the Soviet Union (Russia) find a way to make a diamond from methane without producing graphite impurities in the product. *See also* 1968 MATR.

Hideki Shirakawa, Alan G. MacDiarmid [b. Masterton, New Zealand, April 14, 1927], and Alan J. Heeger [b. Sioux City, Iowa, January 22, 1936] prepare a highly conducting form of polyacetylene by doping it with iodine. *See also* 1976 MATR; 2000 MATR.

Σ Mathematics

Ronald L. Rivest, Adi Shamir, and Leonard M. Adleman suggest that a cryptographic system based on the difficulty of factoring large numbers would be feasible. Such a system is known as a public-key code because the means of encoding can be made public without losing security. *See also* 1760 MATH.

♥ Medicine & health

Two homosexual men in New York City are diagnosed as having the then-rare cancer Kaposi's sarcoma; in retrospect, they are probably the earliest known AIDS victims in New York. The disease will not be officially recognized until 1981.

Andreas R. Gruentzig [b. Dresden, Germany, June 25, 1939, d. October 27, 1985] invents bal-

loon angioplasty, a method for unclogging diseased arteries. *See also* 1967 MED; 1985 MED.

Raymond Damadian builds his first medical magnetic resonance imager (MRI), based on nuclear magnetic resonance spectroscopy techniques, and tests it successfully on July 7. *See also* 1971 MED.

The last recorded case of smallpox found in the wild is in Somalia; after this the smallpox virus is believed to be extinct in the wild, although the virus is retained for research purposes in several laboratories. Smallpox becomes the first human disease to be eradicated completely. *See also* 1796 MED; 1992 BIO.

Rosalyn Yalow and Roger Guillemin of the United States and Polish-American biochemist Andrew V. Schally [b. Wilno, Poland (Lithuania), November 30, 1926] win the Nobel Prize for physiology or medicine for advances in the synthesis and measurement of hormones. *See also* 1950 MED; 1968 MED.

❀ Physics

Leon Lederman discovers the upsilon particle, which confirms the part of the standard model of particle physics that proposes three families of leptons (light particles such as electrons and neutrinos) matched with three families of quarks. Upsilon is a meson formed by a bottom quark combined with its antiquark, so it establishes the third quark family. Family one consists of the up and down quarks that form ordinary matter; family two consists of higher energy strange and charm quarks; in addition to bottom — also known as beauty — the third

family is expected to have a second member, top or truth. *See also* 1975 PHY; 1995 PHY.

American Martin Perl [b. 1927] observes the tau lepton, or tauon, in August, with the accelerator SPEAR at Stanford. The tauon is a "fat muon" just as a muon is a "fat electron"; that is, the muon has all the properties of the electron, but has 200 times the mass. Similarly, the tauon is like an electron, but has about 3500 times the mass. The tauon indicates that the third family of leptons is present to match the three families of quarks. Its discovery is confirmed in 1979. *See also* 1979 PHY.

Philip Warren Anderson, John Hasbrouck Van Vleck, and Nevill Francis Mott share the Nobel Prize for physics, Mott and Anderson for work on amorphous semiconductors, Van Vleck for work on the magnetic properties of atoms. *See also* 1961 PHY; 1968 PHY; 1971 PHY.

↗ Transportation

Soviet cosmonauts Viktor V. Gorbatko and Yuri N. Glaskov begin the *Soyuz 24* mission on February 7; the craft docks with *Salyut 5* for 18 days of experiments. The *Soyuz 25* mission is launched on October 9 with Vladimir Kovalyonok and Valery Ryumin in its crew; attempts to dock with *Salyut 6* are unsuccessful. Yuri V. Romanenko and Georgi M. Grechko begin the *Soyuz 26* mission on December 10, docking with *Salyut 6*. The crew sets an endurance record of 96 days.

Paul D. MacCready [b. New Haven, Connecticut, September 29, 1925] designs and builds the 25-kg (55-lb)

human-powered airplane the *Gossamer Condor*. Powered and flown by a briskly pedaling bicycle racer over a figure-8 course of 1.85 km (1.15 mi), the plane wins the £50,000 Kremer Prize. *See also* 1959 TRAN; 1979 TRAN.

In Japan, the Miyazaki Maglev Test Track in Hyuga City opens with 7 km (4 mi) of track. Maglev trains are suspended above the tracks with magnets, which also propel the trains forward and brake them. *See also* 1990 TRAN.

The world's largest steel-arched bridge, 924 m (3030 ft) long with a main span of 518 m (1700 ft) crosses the New River Gorge in West Virginia. *See also* 1981 TRAN.

1978

▲ Archaeology

Carbon dating of artifacts excavated by American archaeologist James Adovasio in a rock shelter named Meadowcroft near Pittsburgh show that it was inhabited by humans as early as 17,000 years ago, nearly 6000 years earlier than other sites of North America. *See also* 1988 ARCH.

★ Astronomy

On June 22 James W. Christy [b. 1938] and Robert S. Harrington of the U.S. Naval Observatory discover Charon, the only known satellite of Pluto. *See also* 1985 AST.

Jesse Leonard Greenstein, American astronomer [b. New York, New York, October 15, 1909, d. Arcadia, California, October 21, 2002], after studying some 500 white dwarf stars, resolves problems in the theory of how a red giant star evolves into a white dwarf.

A U.S. surveillance satellite detects an unexplained huge explosion over the South Atlantic Ocean. Although thought at the time to be a secret nuclear weapons test, possibly by South Africa or Israel or the two together, experts later decide that the explosion is the impact of a bolide from space, such as a small asteroid. The energy released is calculated as equivalent to 100 kilotons of TNT. *See also* 1908 AST.

U.S. space probe *Mariner 10* is the first spacecraft to visit Mercury, coming within 740 km (460 mi) of the planet.

U.S. space probe *Pioneer 11* is the first spacecraft to visit Saturn, coming within 21,400 km (13,300 mi) of the planet.

On May 20 the United States launches *Pioneer 12* (*Venus 1*), the first space probe to go into orbit around Venus.

The *Einstein Observatory* (HEAO-2) is launched, equipped with a high-resolution X-ray telescope. The observatory discovers a large number of astronomical X-ray sources. *See also* 1995 AST.

On January 26 the *International Ultraviolet Explorer* (IUE) — the first astronomical satellite to be placed in a geosynchronous orbit — is launched.

On August 12 the United States launches the third *International Sun-Earth Explorer* (ISEE-3), which will be renamed the *International Cometary Explorer* (ICE) in 1983 when it is redirected to study the tail of the comet Giacobini-Zinner.

Biology

Scientists complete the task of finding the entire genetic structure of the virus SV40, enabling

them to also find the structure of the virus's protein coat, since the common genetic code for all life is known. *See also* 1977 BIO; 1981 BIO.

Stephen C. Harrison reports the first high-resolution image of the structure of an intact virus, the tomato bushy stunt virus (TBSV). *See also* 1945 BIO.

Daniel Nathans and Hamilton Smith of the United States and Werner Arber of Switzerland win the Nobel Prize for physiology or medicine for their discovery and use of restriction enzymes for DNA. *See also* 1970 BIO; 1968 BIO.

Chemistry

Peter Mitchell wins the Nobel Prize in chemistry for his study of biological energy transfer. *See also* 1961 CHEM.

Communication

Texas Instruments introduces the TMC 0280 speech synthesizer chip, together with the TMC 0350 read-only memory chip of 131,072 bits and the THC 0270 system that can pronounce 165 words. The system forms the heart of the Speak & Spell learning aid for children. *See also* 1976 COMM; 1980 COMM.

The Nippon Electricity Company (NEC) introduces the Voice Data Input Terminal. It can recognize 120 words spoken in groups of up to five words. Words are compared to reference patterns stored in computer memory; the processing time per word is 300 milliseconds. *See also* 1976 COMM; 1980 COMM.

Epson introduces the MX-80, a low-cost dot-matrix printer that is controlled by a computer. The output is somewhat odd looking, but read-

able. The flexibility of the dot-matrix printer, which uses separate rods arranged in a grid to form letters, helps it replace printers based on printing entire letters at a time. *See also* 1976 COMM.

The TCP/IP (Transmission-Control Protocol/Internet Protocol) is adopted for communication between computer networks. It will remain in use for personal computers.

John Robbins (Rob) Barnaby develops the WordStar word-processing program for the CP/M operating system. Later adapted for DOS, it will become the most widely used word-processing package of the early 1980s. *See also* 1976 COMM; 1979 COMM.

Apple brings out the first disk drive for use with personal computers, the Disk II. *See also* 1970 COMM.

Computers

DEC introduces a 32-bit computer with virtual address extension (VAX). The computer can run larger programs than its semiconductor memory can hold. VAX machines become an industry standard for scientific and technical applications at this time, using an operating system called VMS. *See also* 1968 COMP.

Construction

In February the Illinois Regional Library for the Blind and Physically Handicapped and the Community Library in Chicago, a building designed by Stanley Tigerman, opens. It is laid out for ease in memorization — helpful to the blind — and for travel in wheelchairs.

Earth science

On June 26, the United States

launches *Seasat*, an Earth-orbiting satellite that analyzes ocean currents and ice flow based on an imaging radar system.

Ecology & the environment

Love Canal, a community near Niagara, New York, is evacuated after leaking containers of toxic chemicals are uncovered, alerting the public to the dangers of soil and groundwater pollution. In 1990 the EPA will declare the restored site safe for human habitation.

Chlorofluorocarbons (Freons) are banned as spray propellants in the United States on the grounds that they damage the ozone layer in the atmosphere, the layer that screens out most of the harmful ultraviolet radiation from the Sun. *See also* 1976 MATR; 1990 ECOL.

The practice of the Soviet Union (Russia) of using nuclear reactors in space is called to the world's attention when such a satellite crashes to earth in Canada, although it causes no actual damage.

The U.S. government institutes the first steps toward banning lead from gasoline, mainly to protect the platinum catalysts in catalytic converters in automobile exhausts, not to protect the environment. *See also* 1921 ENER; 1984 MED.

To promote renewable resources, 25,000,000 people around the world celebrate Sun Day. *See also* 1970 ECOL; 1981 ENER.

Electronics

Intel introduces its first 16-bit processor, the 8086. IBM will use a slightly simplified version, the 8088, for the central

processor unit in its first marketed personal computer, the PC. *See also* 1972 ELEC; 1981 ELEC.

L.E. Lyons, Alan MacDiarmid, and Nevill Mott experiment with organic semiconductors, carbon compounds doped with oxygen. *See also* 1970 ELEC; 1988 MATR.

♥ Medicine & health

Alison A. Paul and D.A.T. Southgate determine the amount of fiber in various foods, leading the way to finding a possible connection between fiber and prevention of cancer of the colon.

David Botstein [b. Zurich, Switzerland, September 8, 1942], Ronald W. Davis [b. Marda, Illinois, July 17, 1941], and Mark H. Skolnick propose at a conference in April that DNA sequencing can be used to develop gene markers for various genetic diseases. *See also* 1974 BIO; 1979 BIO.

The first human baby conceived outside the body — Louise Joy Brown, called the “test-tube baby” — is born to Lesley Brown in the United Kingdom. In a technique developed by Robert Edwards and Patrick Steptoe, the ovule is extracted from the mother to be, inseminated in a petri dish, and then reimplanted. *See also* 1969 MED.

✿ Physics

Wolfgang Paul [b. Lorenzkirch, Saxony (Germany), August 10, 1913, d. Bonn, Germany, December 6, 1993] traps neutrons in a magnetic storage ring and succeeds in measuring the average lifetime of a free neutron (about 15 minutes). *See also* 1973 PHY; 1989 PHY.

Laser cooling of trapped positive ions is demonstrated for the first time. *See also* 1973 PHY; 1995 PHY.

Arno Penzias and Robert Wilson of the United States and Pyotr Leonidovich Kapitsa [b. Kronshtadt, Russia, July 8, 1894, d. Moscow, April 8, 1984] of the Soviet Union (Russia) share the Nobel Prize in physics, the Americans for discovery of microwave radiation from the big bang and Kapitsa for work in low-temperature physics. *See also* 1964 AST.

I Tools

The first wiggler, a device that increases the brightness of X-ray synchrotron radiation, is installed in the SPEAR storage ring at the Stanford Synchrotron Radiation Laboratory. *See also* 1980 TOOL.

✈ Transportation

On January 10 Soviet cosmonauts Vladimir Dzhanibekov and Oleg G. Makarov are launched on the *Soyuz 27* mission; their craft carries a second crew to dock with the *Salyut 6* space station. Czech Vladimir Remek, the first non-American, non-Russian in space, along with Soviet cosmonaut Alexei A. Gubarev, begins the *Soyuz 28* mission on March 2; they are the third crew to board *Salyut 6*.

Vladimir Kovalyonok and Aleksander S. Ivanchenkov are launched on June 15 for the *Soyuz 29* mission; their craft docks with *Salyut 6*, and at 140 days, the crew sets a new space endurance record. Miroslaw Hermaszewski, the first Polish cosmonaut, and Pyotr I. Klimuk begin the *Soyuz 30* mission on June 27, the second international crew carried to *Salyut*. The first East German in space, Sig-

mund Jahn, and Soviet cosmonaut Valery F. Bykovsky are the third international crew on the *Soyuz 31* mission, which begins August 25.

1979

◀ Anthropology

The fossil footprints at Laetoli, Tanzania, are carefully reburied to preserve them for future anthropologists. *See also* 1976 ANTH; 1995 ANTH.

▲ Archaeology

Lothar Haselberger, while visiting the Temple of Apollo at Didyma (Turkey), discovers the almost complete plans for the temple inscribed in stone on some of the temple walls. The temple planned in 334 BCE would have been the largest Greek temple built, although incomplete after 600 years, when work ceased.

★ Astronomy

Dennis Walsh at the Jodrell Bank Observatory makes the first observation of a gravitational lens — a galaxy that refracts light because of the gravitational distortion of space (described by general relativity). The lens can amplify or multiply images of suitably placed objects more distant than the lensing galaxy. *See also* 1987 AST.

Robert Dicke and James Peebles explain the smoothness at a large scale of the universe by assuming space is flat; that is, the density of the universe is equal to the critical density, or just under the level required to halt expansion in the future. They note that this theoretical explanation has not been established by direct observation. *See also* 2000 AST.

On November 20 meteorite Yamato 791197 is collected in Antarctica. Later it will be recognized as the first meteorite to have landed on Earth and been found by scientists; it originated by being blasted off the face of the Moon. However, by the time Yamato 791197 is known to come from the Moon, other meteorites have already revealed their lunar origin. *See also* 1982 AST.

On February 24 the United States launches P78-1, which studies solar radiation until it is purposely shot down by the U.S. air force on September 13, 1985, to demonstrate that it is possible to destroy a satellite that way. Still working at the time of its destruction, the satellite is deemed by many scientists to be too valuable to have been used as a target.

In March the *Voyager 1* spacecraft discovers a ring around Jupiter. *See also* 1977 AST; 1980 AST.

The *High-Energy Astrophysical Observatory 3* (HEAO-3) picks up gamma-ray signals from Cygnus X-1. *See also* 1978 AST.

The Canada-France-Hawaii Telescope (CFHT) on Mauna Kea, Hawaii, begins operation. Its 3.6-m (142-in.) mirror is set up to work at both optical and infrared frequencies.

✿ Biology

Sir Walter Bodner suggests a way to use a combination of chemical studies of DNA with restriction enzymes and studies of heredity in large families to locate gene markers for specific traits.

▷ Chemistry

English-American chemist Herbert Charles Brown and Georg Wittig win the Nobel

Prize in chemistry, Brown for his study of boron-containing organic compounds and Witig for his study of phosphorus-containing organic compounds. *See also* 1962 CHEM; 1954 CHEM.

Communication

The High Order Language Working Group (HOLWG) established by the Pentagon studies the possibility of a standard computer language that would replace the about 1000 languages used by the U.S. Defense Department. Frenchman Jean Ichbiah [b. March 25, 1940] and coworkers develop ADA, a computer language named for Lady Ada Lovelace (the daughter of Lord Byron who, legend has it, was the first computer programmer). It will be used by the U.S. armed services and NATO forces. *See also* 1843 COMP.

The first commercial network of cellular telephones is set up in Tokyo, Japan. Later in the year Bell Labs tests a cellular system on 2000 users in Chicago, Illinois. *See also* 1946 COMM; 1983 COMM.

Philips and Sony bring the video disk to market. Images and sound are recorded digitally as analog tracks in the surface of the disk, which are read by a laser as the disk rapidly rotates. *See also* 1995 COMM.

Sony Corporation introduces the Walkman, the first completely portable sound system designed to play audio cassettes and to be listened to with earphones. The first version has two earphone jacks and a button to press to stop the sound for conversation, since Sony assumes that few will want to listen alone.

Within a year it becomes apparent that solitary listening is the reason for the Walkman's being and the extra phone jack and cutoff button are dropped.

Hayes begins selling a modem that connects computers directly to a phone line for communicating with other computers. *See also* 1958 COMM.

Daniel Bricklin [b. 1951], a computer scientist and accountant, and programmer Robert Frankston develop VisiCalc (Visible Calculator), the first spreadsheet program for the microcomputer; VisiCalc enables personal computer users to develop business applications without learning a programming language. By 1985 800,000 copies will be sold. *See also* 1978 COMM; 1980 COMM.

The first handheld video game comes on the market.

Computers

In June the Apple II Plus is introduced. It has BASIC built into the read-only memory (ROM) instead of supplied on a separate cassette tape.

Construction

Work begins on the Rogun Dam (in Tadzhikstan, Russia) near the borders of Russia, Afghanistan, and China. At 335 m (1098 ft) it will become the highest dam in the world. *See also* 1936 CONS; 1983 CONS.

Work begins on the 44-story apartment tower over New York City's Museum of Modern Art. It becomes one of the world's tallest buildings to be constructed from cast-in-place concrete.

Ecology & the environment

The nuclear reactor at Unit 2 of Three Mile Island loses its water buffer and undergoes a partial meltdown through operator error on March 28; a small amount of radioactive material escapes the containment dome, but the reactor itself is irreparably damaged; no one is injured. *See also* 1957 ECOL; 1986 ECOL.

James Lovelock [b. Letchworth Garden City, England, July 26, 1919] publishes his Gaia hypothesis, which argues that Earth resembles a living organism — a self-regulating entity with complex feedback mechanisms between organisms and the physical environment.

Electronics

Peter LeComber and coworkers from the University of Dundee (Scotland) show that amorphous silicon can be used to build thin-film transistors that control liquid-crystal displays. *See also* 1984 COMM.

In September Motorola introduces the 68000 microprocessor chip; it has a 24-bit capacity for reading memory and can address 16 megabytes of memory; it will be the basis of the Macintosh computer developed by Apple. *See also* 1984 ELEC.

Steven Hofstein invents the field-effect transistor, using metal oxide technology (MOSFET). *See also* 1970 ELEC.

Mathematics

Robert S. Boyer and J. Strother Moore develop the Boyer-Moore Theorem Prover (a.k.a. Nqthm, which stands for New, Qualified Theorem Prover). It

uses recursive function theory and heuristic techniques to automate proofs, specifically proofs by mathematical induction, using a computer. *See also* 1575 MATH.

Medicine & health

A severe anthrax epidemic breaks out in Sverdlovsk, Soviet Union, killing 64 people; U.S. experts think that it is the result of an accident at a germ warfare facility, but Soviet doctors claim it results from contaminated meat. Evidence released in 1988 tends to confirm the Soviet claims.

Human insulin is synthesized by genetic engineering methods. The human gene for insulin is inserted in the genome of *Escherichia coli*, which then produces the protein. *See also* 1976 BIO; 1980 MED.

In March Herbert Needleman releases an influential study that shows that small amounts of lead in children's blood and teeth correlate with lower IQ test scores, suggesting that low-level lead poisoning can reduce intelligence. *See also* 1978 ECOL; 1980 ECOL.

Allan Cormack of South Africa and the United States and Godfrey Hounsfield of England win the Nobel Prize for physiology or medicine for their invention of computed axial tomography. *See also* 1957 MED; 1972 MED.

Physics

Four groups at the Deutsches Elektronen Synchrotron (DESY) in Hamburg produce convincing evidence for the existence of the gluon, a particle that carries the color force between quarks (which also produces the strong force between such particles as pro-

tons and neutrons), confirming the theory of quantum chromodynamics. *See also* 1972 PHY.

Hans Dehmelt and three assistants capture and photograph a single atom, the first time this feat has ever been accomplished. *See also* 1980 PHY.

Steven Weinberg and Sheldon Glashow of the United States and Abdus Salam of Pakistan win the Nobel Prize in physics for discovering the link between electromagnetism and the weak force of radioactive decay. *See also* 1967 PHY.

→ Transportation

Skylab, an early U.S. space station that had been abandoned, falls into the atmosphere as a result of an intense solar wind caused by increased sunspot activity; it breaks into pieces that land in western Australia but cause no damage. *See also* 1973 TRAN.

Soviet cosmonauts Vladimir Lyakhov and Valery Ryumin begin the *Soyuz 32* mission on February 25; the mission carries the crew to *Salyut 6* and sets a new endurance record of 175 days in space. Nikolai N. Rukavishnikov and Georgi Ivanov, the first Bulgarian in space, begin the *Soyuz 33* mission on April 10; engine failure prior to docking forces early termination after two days. The *Soyuz 34* mission is launched without a crew on June 6 and returns after 74 days with the crew from *Salyut 6*.

The first of the European Space Agency's Ariane rockets successfully lifts off on December 24 from the Guiana Space Center in Kourou, French Guiana. The rocket is designed to launch satellites

into orbit for various customers, including the European Space Agency, but commercial users as well. *See also* 1985 TRAN.

Paul MacCready's human-powered airplane the *Gossamer Albatross* flies across the English Channel. *See also* 1977 TRAN; 1988 TRAN.

The German experimental train propelled and levitated by magnets (a maglev train) is exhibited at an international exhibit in Hamburg, where it carries more than 50,000 passengers along a short test track. *See also* 1977 TRAN.

1980

■ Archaeology

The City of David Archaeological Project rediscovers Warren's Shaft, a vertical well that formed part of the waterworks for Jerusalem from before David's time. Once cleaned out, the shaft provides access to the entire early waterworks. *See also* 1867 ARCH.

Israeli divers in the Mediterranean off Athlit, Israel, just south of Haifa, recover the ram from a quinquereme or perhaps a quadrireme (naval vessels with five or four banks of rowers) that had been sunk around the 150 BCE. It is the first physical evidence of a ship from this period. *See also* 650 BCE TRAN.

Italian archaeologists discover in Herculaneum the bodies of hundreds who died at the shore of the sea, destroyed by the eruption of Vesuvius in 79 CE.

★ Astronomy

Alan H. Guth [b. 1947] proposes a cosmological model of



VERY LARGE ARRAY Part of the National Radio Astronomy Observatory, the 27 steerable dish antennas on the Plains of San Agustin near Socorro, New Mexico, (26 shown here) each 25 m (82 ft) in diameter, combine to produce the equivalent in resolution of a single radio-telescope antenna 36 km (22 mi) across.

the birth of the universe, called the inflationary universe, in which the universe expands very rapidly for a short time before the big bang. *See also* 1981 AST.

Martin Rees [b. Shropshire, England, June 1942], Mitchell Begelman, and Roger Blandford predict the existence of double (or binary) black holes. *See also* 2002 AST.

Susan Wyckoff of Arizona State University and Peter Wehinger of the Max Planck Institute discover a nebulous region around the first discovered quasar, 3C 273. This is interpreted as meaning that the quasar may be in the center of a galaxy that is too distant to image in detail. *See also* 1963 AST.

Timothy J. Pearson and coworkers track a glowing blob ejected by the quasar 3C 273 from July 1977 to July 1980 and observe that it is apparently traveling at 9.6 times the speed of light, but they conclude instead that this apparent motion reflects a speed of

about 0.995 the speed of light toward Earth. *See also* 1966 AST.

The VLA — Very Large Array — radio telescope in Socorro, New Mexico, begins operation. It uses 27 antennas and interferometry to produce resolution equivalent to a single dish 36 km (22 mi) in diameter. *See also* 1975 AST.

The U.S. *Voyager 1* space probe flies by Saturn on November 12; *Voyager 2* flies by on August 27, 1981. Both passages provide much information on the planet, its moons, and the ring system. *Voyager 1* finds the 13th and 14th moons of Saturn and the 15th and 16th moons of Jupiter. *See also* 1977 AST.

The U.S. *Solar Maximum Mission* satellite (*Solar Max*) is launched on Valentine's Day to study the solar maximum and the Sun's output of radiation. The satellite experiences failure in the attitude control system in November and appears unable to complete its mission. After its failure, however, it will be repaired and relaunched from a space shuttle in April 1984. The

ultimately successful satellite will be finally pushed to its destruction by a massive solar flare on December 2, 1989.

Biology

Martin Cline and coworkers transfer genes from one mouse to another and succeed in having the genes function in the new organism. *See also* 1976 BIO; 1981 BIO.

American geneticists discover hypervariable regions in genes (short sequences of DNA that are repeated over and over in the same chromosome).

The successful production of human interferon in bacteria is announced by Charles Weissmann [b. October 14, 1931] of the University of Geneva. *See also* 1957 MED.

Chemistry

Paul Berg, Walter Gilbert, and Frederick Sanger of England share the Nobel Prize in chemistry, Berg for the development of recombinant DNA and Gilbert and Sanger for the development of methods to map the structure of DNA. *See also* 1972 BIO; 1977 BIO.

Communication

IBM achieves 91 percent accuracy with a voice recognition system using an IBM System/370 Model 168 computer. It has a 1000-word vocabulary and can process the words at a normal speaking pace and display the spoken words on a screen. Votrax develops the SC-01 single-chip voice synthesizer with unlimited vocabulary; a separate chip stores phonemes as 6-bit words, and a special circuit selects and connects the phonemes, creating words. *See also* 1978 COMM; 1982 COMM.

The current international fax standard (Group 3) is set; it allows facsimile messages to be transmitted at about one page per minute or faster. *See also* 1974 COMM; 1990 COMM.

France starts Minitel, an experimental telephone inquiry system consisting of terminals placed in homes. The system will soon be established throughout France and offer a large number of online services.

Wayne Ratliff develops dBase II, a database software package including a programming language derived from Vulcan I, a database program developed for mainframes at the Jet Propulsion Laboratories in the late 1960s. dBase will become the principal electronic filing system for personal computers during the 1980s.

Computers

In the United Kingdom, Clive Sinclair [b. Surrey, England, July 30, 1940] develops a minimalist and cheap computer, the ZX81 (sold starting in 1981 as the Timex-Sinclair in the United States). It uses a television receiver as a monitor. More than 1,000,000 units will be sold during the following years. *See also* 1976 ELEC.

Earth science

Walter Alvarez, Luis Alvarez, Frank Asaro, and Helen



MT. ST HELENS ERUPTS The violent eruption of this Cascade Range volcano in Washington State removed the top 1400 m (4600 ft) of the mountain and blew out a large part of one side. The debris field and mud flows changed the topography of the region around the mountain as well.

Michel explain the extinction that took place 65,000,000 years ago, including the dinosaur extinction, by the impact of an asteroid on Earth.

Demonstrating the environmental impact of natural forces, the volcanic eruption of Mount St. Helens in Washington State kills 61 humans and millions of other animals, destroys thousands of acres of habitats, and pollutes streams and lakes.

Ecology & the environment

The U.S. government bans paints containing lead. *See also* 1979 MED; 1984 ECOL.

Congress enacts the Comprehensive Environmental Response, Compensation and Liability Act (CERLA, or Superfund) to clean up hazardous waste sites.

The U.S. Supreme Court rules that a microbe developed by General Electric for oil cleanup can be patented. *See also* 1988 MED.

Mathematics

Leonard Adleman and Robert S. Rumely develop a new and improved computer test for large natural numbers that can determine whether they are prime or not. *See also* 2002 MATH.

Robert Griess, Jr., constructs a finite simple group known as the monster because of its size; with this group, the proof of the classification of all the finite simple groups, running thousands of pages and starting in 1830, is complete. *See also* 1894 MATH.

Medicine & health

Dornier Medical Systems of Munich (Germany) develops the lithotripter, a machine that uses sound waves to break up kidney stones while the stones are still in the kidney.

Walter Alvarez

[b. Berkeley, California, 1940]

In 1980 Alvarez and coworkers located in Italy a thin layer of sediment associated with the boundary between the Cretaceous and Tertiary periods, a time of mass extinctions now known as the K-T boundary. Alvarez sent some of the sediment to his father, Luis Alvarez, a physicist, who found the sample enriched with iridium, a rare element in Earth's crust. Subsequent research showed the iridium layer to be worldwide. The Alvarezes proposed that the mass extinctions were caused when a large body enriched in iridium struck Earth and produced great clouds of dust that obscured the Sun for several years.

The return of catastrophism

In the late 18th and early 19th centuries, a prevailing idea was that the surface of Earth had been shaped by one or more catastrophes. The most popular catastrophe invoked was Noah's Flood, but great volcanic catastrophes were also postulated. The evidence for such catastrophes, the proponents of catastrophism claimed, included the fossil record, remains of creatures exterminated during those catastrophes. Among the exponents of catastrophism were Charles Bonnet and Georges Cuvier. A few earth scientists, notably James Hutton and Charles Lyell, introduced the doctrine of uniformitarianism as an antidote to catastrophism. Hutton and Lyell argued that the surface of Earth formed by small changes occurring over vast reaches of time, the basic doctrine of uniformitarianism.

Darwin learned uniformitarianism from his friend Lyell and applied the concept to evolution, offering an alternative explanation for the fossil record. For the hundred years after Lyell and Darwin, uniformitarianism became dominant in geology, paleontology, and evolutionary theory. A small move away from uniformitarianism was initiated in the 1970s by Niles Eldredge and Stephen Jay Gould in evolutionary biology with their theory of "punctuated equilibrium," but their new ideas, while influential, were not accepted by many uniformitarians.

In 1980, however, a chance discovery brought catastrophism to the forefront of scientific thought again. Walter Alvarez at a site in Italy was investigating the boundary between the Cretaceous and Tertiary periods, called the K-T boundary by geologists (after the German *Kreidet-Tertiär*). He asked his father, the distinguished physicist Luis Alvarez, to help analyze a clay layer that appeared right at the K-T boundary. The senior Alvarez had the equipment necessary to check the clay for heavy metals, so he did. The clay turned out to have much more of the heavy metal iridium than samples of clay usually do. Examination of samples of the K-T boundary from around the world showed the same iridium enrichment.

The Alvarezes and their coworkers proposed that the iridium was caused by a catastrophe — they postulated that a large body, such as an asteroid or a comet, loaded with iridium, had crashed into Earth. Furthermore, they claimed that the impact, by blanketing Earth with dust and soot, caused the extinctions that were the original rationale for the K-T boundary. Loss of sunlight would cool Earth and also stop photosynthesis. The combination would remove the base of the food chain, green plants, which in turn would lead to other extinctions. The Alvarezes' theory was immediately popular because it explained why dinosaurs became extinct at or near the end of the Cretaceous. Although the general public is not aware of mass extinctions, nearly every literate person knows that the dinosaurs became extinct.

While the possibility of such an impact was still being studied, a new factor developed. David M. Raup and J. John Sepkoski, Jr., analyzed mass extinctions of the type that occurred at the K-T boundary. They found that such extinctions were periodic, with a period of about 26,000,000 years. It is difficult to think of any Earthly factor that would have such a period; however, scientists could suggest factors outside of Earth. The most prominent idea was that something periodically disturbs the cloud of comets — the Oort cloud — that fills the edge of the solar system. When this happens, some comets fall toward the Sun. A few of them might strike Earth, causing such catastrophes as mass extinctions. Candidates for the disturbing force proposed by various scientists included passage of the solar system through the plane of the galaxy, a companion star to the Sun called Nemesis, and a planet called X. Other scientists questioned whether the periodicity that Raup and Sepkoski proposed was real or simply an accident of the way they analyzed extinctions.

Although much of the new catastrophism is still in dispute, the idea that started it all, the impact of an object at the K-T boundary, has gradually gained acceptance by most geologists and many paleontologists. Whether or not Nemesis or X exists, something apparently did strike Earth at the K-T time boundary, and most think it caused the mass extinctions at that time.

The pharmaceutical firm Eli Lilly starts the production and testing of human insulin using genetically altered bacteria; the insulin can be used by diabetics that are allergic to insulin obtained from animals. *See also* 1979 MED; 1982 MED.

George Snell of the United States, Venezuelan-American geneticist Baruj Benacerraf, and Jean Dausset of France win the Nobel Prize for physiology or medicine for their

discovery of the role of antigens in organ transplants. *See also* 1952 MED; 1962 MED; 1967 MED.

❖ Physics

Klaus von Klitzing [b. Schröda, Poland, June 28, 1943] discovers an effect, known as the quantized Hall effect, in which changes in resistance in a plate kept in a magnetic field at temperatures near absolute zero occur in discrete steps instead of continuously; it is one of the

few examples of quantum behavior that is directly observable. *See also* 1985 PHY.

In March Frederick Reines announces his finding that the neutrino has mass. Also, Valentin Lubimov and his coworkers claim to have measured the mass of the electron neutrino; they find a value between 14 and 46 electron volts. Other scientists fail to confirm these figures at this time. *See also* 1998 PHY.

Hans Dehmelt and assistants capture and photograph in color a single charged barium atom, which the team names Astrid. The photograph of Astrid shows the atom as a tiny blue dot on a black background. *See also* 1979 PHY.

Linn Mollenauer, Rogers Stollen, and James Gordon at AT&T Bell Labs show experimentally that solitons — which are individual waves with a single peak — can trav-

el through optical fibers. See also 1834 COMM; 1987 PHY.

James Cronin and Val Fitch of the United States win the Nobel Prize in physics for their studies showing that charge-parity and time symmetry can be violated. See also 1964 PHY.

I Tools

The first undulator, a device for increasing the power of synchrotron radiation, is installed in the SPEAR storage ring used at the Stanford Synchrotron Radiation Laboratory. See also 1978 TOOL.

Hughes Aircraft Corporation introduces a cutting machine for textiles that uses a laser beam. See also 1976 TOOL.

✈ Transportation

Soviet cosmonauts Valery Ryumin and Leonid Popov begin the *Soyuz 35* mission on April 9; they are carried to the space station *Salyut 6*. Valery N. Kubasov and Bertalan Farkas, the first Hungarian in space, are launched on May 26 on the *Soyuz 36* mission; they are carried to *Salyut 6* and return on *Soyuz 35* capsule. Yuri Malyshev and Vladimir Aksenov begin the *Soyuz T 2* mission on June 5. A test of a modified Soyuz-type craft, *T 2* docks with *Salyut 6*. Viktor V. Gorbatko and Pham Tuan (the first Vietnamese in space) are launched on the *Soyuz 37* mission on July 23. Cosmonauts are exchanged with *Salyut 6*, and the *Soyuz 35* crew is returned to Earth after 185 days in orbit. Yuri V. Romanenko and Arnaldo Tomayo-Mendez, the first Cuban in space, begin the *Soyuz 38* mission. They ferry the new crew to *Salyut 6*. Leonid Kizim, Oleg G.

Makarov, and Gennadi M. Strekalov, the first three-person crew since *Soyuz 11*, begin the *Soyuz T 3* mission on November 27. They dock with *Salyut 6* and exchange crews.

The world's longest vehicular tunnel for automobiles, through the St. Gotthard Pass in the Swiss Alps south of Zurich, is opened. The main tunnel is 16.4 km (10.2 mi) long.

1981

◀ Anthropology

A team of anthropologists and archaeologists describe their discovery of the first known religious sanctuary, in El Juyo Cave in the Cantabrian Mountains of northern Spain, dated at about 12,000 BCE. It includes an apparent altar with remains of sacrifices and placed before the altar an image that archaeologists think is half a human face combined with that of a lion or leopard.

★ Astronomy

Andrei D. Linde [b. Moscow, March 2, 1948] (and independently Andreas Albrecht and Paul J. Steinhardt) develops a theory of the origin of the universe, called the new inflationary universe, which greatly improves upon the ideas of Alan Guth put forward in 1980. See also 1980 AST; 2001 AST.

Robert Kirshner, Augustus Oemler, and Paul Schechter discover in a sky survey concentrated in the direction of the constellation Boötes that there is a giant void 300,000,000 light-years across that contains no observable matter at the time of discovery. See also 1986 AST.

Voyager 2 reaches the vicinity of Saturn, observes the planet and its rings, and then uses its gravity to accelerate it toward Uranus and Neptune. See also 1980 AST; 1986 AST.

Biology

Scientists from Ohio University in Athens are the first to transfer genes from one animal species to another by transferring genes from other species into mice. See also 1980 BIO.

George Streisinger [b. December 27, 1927, Budapest, Hungary, d. August 11, 1984] of the University of Oregon and coworkers produce a genetic copy (clone) of a zebra fish. Streisinger is instrumental in making the zebra fish an important experimental animal for studies of vertebrate genetics. See also 1963 BIO; 1982 BIO.

Charles G. Sibley [b. Fresno, California, August 7, 1917, d. Santa Rosa, California, April 12, 1998] and Jon E. Ahlquist use studies of DNA to determine the evolutionary history of such flightless birds as the ostrich and the emu, suggesting various revisions in the relationships between species. See also 1984 ANTH.

The genomes for the poliomyelitis and influenza A viruses are sequenced. See also 1978 BIO; 1984 BIO.

Alexander H. Harcourt and coworkers determine that statistical differences in average body weight and testis weight can be used to predict monogamy, polygyny, or promiscuity in primates. Species with large testes for their body size, such as chimpanzees, are promiscuous.

Roger Wolcott Sperry, David Hunter Hubel, and Torsten Nils Wiesel of the United States win the Nobel Prize in physiology or medicine for their studies on the organization and local functions of brain areas. See also 1962 MED; 1968 BIO.

□ Chemistry

Kenichi Fukui of Japan and Roald Hoffmann of the United States win the Nobel Prize in chemistry for the application of laws of quantum mechanics to chemical reactions. See also 1962 CHEM; 1963 CHEM.

↳ Communication

A proposed set of technical standards for compact disc (CD) recording and playback established in 1980 by Sony, Philips, and PolyGram is accepted worldwide, paving the way for introduction of compact discs commercially. See also 1972 COMM; 1982 COMM.

Visicorp develops the first integrated software package, Vision, which combines a word processor, spreadsheet, and database. See also 1982 COMM.

▀ Computers

The IBM Personal Computer (the PC), using what is to become an industry-standard disk operating system (PC-DOS), is introduced. The same operating system, developed by Microsoft, is sold separately as MS-DOS (Microsoft Disk Operating System). See also 1975 COMP; 1983 COMP.

Xerox introduces the Star 8010, an office computer based on the Alto that had been

developed a few years earlier by Alan Kay but that was only used in-house. The Star 8010 is the first computer with a graphical interface (using icons) and a mouse. Priced at \$16,000 and unable to use any but its own software (the program codes are not public), it is a commercial failure, but an inspiration to other computer designers. *See also* 1972 COMM.

Osborne builds the first portable computer in which disk drives, video monitor, and processor unit are mounted in a single box; it is about the size and weight of a fully packed suitcase, and when smaller portables are made, this one is reclassified as "luggable." It uses CP/M as an operating system and the Z-80 microprocessor. *See also* 1985 COMP.

Hewlett-Packard introduces the HP12C, which will become one of the most widely used programmable calculators of the 1980s and 1990s, especially by MBAs (persons with a masters degree in business), despite the calculator's use of the notation system called reverse Polish logic instead of more familiar algorithms.

Earth science

Earth's climate during the last Ice Age is mapped by the CLIMAP project. Fossil plankton species are used to estimate ocean temperatures and the extent of ice. One surprise is that the oceans nearer the equators remained warm even while ice covered northern and southern parts of the globe.

Ecology & the environment

The black-footed ferret, previously thought to be extinct, is discovered living in small num-

bers in prairie dog towns in Wyoming. *See also* 1986 ECOL.

Electronics

Computer chips produced by the Japanese with 64 kilobits (65,536 bits) of memory capture the world market for computer memory. *See also* 1978 ELEC; 1984 ELEC.

Energy

Adam Heller [b. Cluj, Romania, June 25, 1933], Barry Miller [b. Passaic, New Jersey, January 22, 1933], and Ferdinand A. Thiel announce a liquid junction cell that converts 11.5 percent of solar energy into electricity. *See also* 1904 ENER; 1989 ENER.

Solarplant One in California, the world's largest solar power station up to this time, generating up to 10 megawatts of electricity, is completed. *See also* 1969 ENER; 1988 ENER.

Materials

Soviet diamond researchers produce both single-crystal diamond films on previously existing diamonds and multiple-crystal diamonds on metal; single-crystal diamonds are much more desirable for many purposes. *See also* 1977 MATR; 1990 MATR.

Medicine & health

The U.S. Centers for Disease Control recognizes the disease called acquired immune deficiency syndrome, or AIDS, for the first time. *See also* 1977 MED.

The genetic code for the hepatitis B surface antigen is found, opening up the possibility of a bio-engineered vaccine. The U.S. Food and Drug Administration on November 16 approves a vaccine for

hepatitis B made from human blood that has been developed by scientists at Merck Institute for Therapeutic Research in Pennsylvania. *See also* 1986 MED.

Adolpho de Bold, Harald Sonnenberg, and coworkers demonstrate that ground-up rat atria (heart chambers) reduce blood pressure in rats, suggesting that the rat atrium produces a previously unknown hormone. The hormone is produced by bodies in cells that had been first observed by Bruno Kirsh. *See also* 1956 MED; 1984 MED.

Surgeons at Stanford University in California perform the first successful heart-lung transplant. *See also* 1968 MED.

Physics

Nicolaas Bloembergen and Arthur Schawlow of the United States and Kai M. Siegbahn of Sweden win the Nobel Prize in physics for their advances in technological applications of lasers for the study of matter. *See also* 1981 PHY; 1958 TOOL; 1958 PHY.

Tools

Gerd Binnig [b. Frankfurt, West Germany, July 20, 1947] and Heinrich Rohrer [b. Buchs, Switzerland, June 6, 1933] of IBM develop the scanning tunneling microscope (STM), a device used to image surfaces closely. The surface of a specimen is scanned by measuring a current between a very small tip and the specimen, using electron tunneling as the sharp point is moved over a surface. The amount of current provides the distance of the point from the surface; this method is sensitive enough to provide pictures of individual atoms

in a surface. *See also* 1951 TOOL; 1985 TOOL.

The 3M Company at Saint Paul (Minnesota) introduces a method for creating optical disks that can be written on by lasers. They develop a material that melts at 150°C (302°F) without undergoing chemical changes. *See also* 1979 COMM.

Transportation

On April 12 U.S. astronauts John W. Young and Robert L. Crippen begin the first mission of the space shuttle, STS-1, in *Columbia*, the Space Transportation System's first reusable space shuttle. The mission lasts 2 days 8 hours and marks the first touchdown of a U.S. spacecraft on land. Joe H. Engle and Richard H. Truly begin the second mission of the space shuttle *Columbia* on November 12. After 2 days and 6 hours the mission ends early due to the loss of a fuel cell.

Soviet cosmonauts Vladimir Kovalyonok and Viktor Savinykh are launched on March 12 on the *Soyuz T 4* mission to *Salyut 6*. Vladimir Dzhanibekov and Jugderdemuduyn Gurragcha, the first Mongolian in space, begin the *Soyuz 39* mission on March 22; the craft docks with *Salyut 6*. Leonid I. Popov and Dumitru Prunariu, the first Romanian in space, begin the *Soyuz 40* mission on May 14.

The world's longest suspension bridge opens over the Humber estuary in the United Kingdom; it is 1410 m (4626 ft) long. *See also* 1964 TRAN.

Paul MacCready's solar-powered airplane *Solar Challenger* makes its maiden flight in the summer. *See also* 1979 TRAN.



SHUTTLE IN SPACE When one of the space shuttles is performing certain experiments in space or launching or retrieving a satellite, the bay doors swing wide open, revealing a different view of the shuttle operation from the one we usually see as the ship travels through the atmosphere.

The first regular passenger line of the *Train à grande vitesse* (TGV), a high-speed train, opens in France; the same year the TGV reaches a record speed of 380 km/h (236 mph). *See also* 1973 TRAN.

1982

■ Archaeology

The 16th-century Tudor warship *Mary Rose*, which sank before the eyes of Henry VIII in 1545, is removed from beneath the sea in Portsmouth Harbor in England after 17 years of work. The ship is found to be full of Tudor artifacts. A lengthy process of restoration begins, with the ship's hull protected at all times with circulating seawater.

George Bass leads a team of archaeologists who excavate the oldest shipwreck found so far — a freighter loaded with copper, tin, resins used in making perfume, and scrap gold and silver, as well as miscellaneous treasures, such as hippopotamus teeth. It was wrecked at Ulu Burun on the southwest coast of Turkey

around 1350 BCE. *See also* 1350 BCE TRAN.

★ Astronomy

On January 18 the meteorite Allan Hills 81005 is collected in Antarctica. It is the first meteorite to be recognized as coming from the Moon, although meteorite Yamato 791191, collected on November 20, 1979, will later be recognized as also coming from the Moon. *See also* 1979 AST.

Soviet spacecraft *Venera 13*, launched October 30, 1981, successfully lands on Venus on March 1. It operates for 127 minutes before the pressure of 8511 kilopascals (1234 lb per sq in.) and the temperature of 457°C (855°F) overcome it. It examines a rock sample and transmits photographs to Earth. *Venera 14*, launched November 4, 1981, lands on March 5 on a basalt plain some 950 km (590 mi) from *Venera 13* and conducts similar experiments but lasts only 57 minutes at a pressure of 9524 kilopascals (1381 lb per sq in.) and a temperature of 465°C (869°F). *See also* 1975 AST.

❖ Biology

Elizabeth H. Blackburn and Jack W. Szostak [b. London, 1952] show that telomeres (nucleotide sequences at both ends of a chromosome) protect chromosomes, as had been proposed by Barbara McClintock and Hermann Muller in the 1930s. *See also* 1985 BIO.

A gene from one mammal species functions for the first time in another mammal species as the gene for rat growth hormone is transferred to mice. Some of the mice grow to double normal size because of the additional hormone they produce. *See also* 1981 BIO.

The space shuttle

During the 1960s, the U.S. National Aeronautics and Space Administration (NASA) launched large numbers of expendable space vehicles. By the early 1970s it seemed like a good idea to replace these expensive rockets with a reusable space booster. After a study of several designs, NASA in 1972 decided to construct a Space Transportation System (STS) based on the space shuttle. The shuttle takes off vertically, orbits Earth a number of times, and returns as a glider, supported by stubby wings. A huge external fuel tank is jettisoned after takeoff and burns up when reentering the atmosphere, but two solid-state booster rockets descend on parachutes and are reusable.

Comparable in size to a DC-9 aircraft, the space shuttle carries payloads of up to 29,500 kg (65,000 lb) in its huge 18.3-m (60-ft) long cargo bay. A 15.25-m (50-ft) mechanical arm is used to manipulate the payload. With this arm, astronauts lift satellites out of the cargo bay and place them into near-Earth orbit.

A total of five space shuttles were built. The first, *Columbia*, began with a two-day mission, making a perfect landing in 1981. This flight marked the start of a series of scientific and military shuttle missions. Shuttle crews placed many satellites in orbit, conducted experiments, and retrieved several satellites for repair. Flights were temporarily halted after *Challenger* exploded shortly after takeoff in 1986, killing the crew of seven people. Although shuttle flights resumed on September 29, 1988, it was apparent that the use of shuttles with human crews was an expensive and dangerous way to place satellites in orbit. NASA once again turned to expendable rockets for routine launches, but still used shuttle flights for some satellite launches as well as for other purposes, including construction work on the International Space Station. But on February 1, 2003, another shuttle and its crew were lost. *Columbia* broke up during reentry, killing its crew of seven and once again halting the shuttle program.

The shuttle has made possible many feats in space that only humans can do, such as capturing and correcting defects in existing satellites.

The Russian alternative — a Russian shuttle flew only a single test flight with no crew aboard — has been to launch humans using giant expendable rockets and then parachute them back to Earth. Russia has lost fewer cosmonauts using this approach than the 14 lost in shuttle disasters, but that approach too has had its share of problems, including once when the parachute failed to open.

NASA has explored alternatives to the shuttle, including fully reusable craft that could land at ordinary airplane speeds, but none of these were close to deployment at the time of the *Columbia* disaster.

Thomas Cech [b. Chicago, Illinois, December 8, 1947] discovers that RNA can act as a catalyst. *See also* 1989 BIO.

John R. Vane of the United States and Sune K. Bergstrom and Bengt I. Samuelsson of Sweden win the Nobel Prize for physiology or medicine for their studies on the formation and function of prostaglandins, hormonelike substances that combat disease. *See also* 1971 MED; 1957 BIO; 1965 BIO.

Chemistry

Scientists from the Society for Heavy Ion Research in Darmstadt (Germany) announce on August 29 the creation of a single atom of element 109, later to be named meitnerium (Mt).

Aaron Klug of South Africa wins the Nobel Prize in chemistry for developments in electron microscopy and the study of acid-protein complexes. *See also* 1974 CHEM.

Communication

In October compact disc (CD) players are introduced by CBS/Sony and Philips; the CD is a 120-mm (4.7-in.) diameter plastic disk that uses tiny pits read by a laser to reproduce sound or other information. The first commercial CD is "52nd Street" by composer-singer Billy Joel. *See also* 1981 COMM; 1984 COMM.

Christopher J. Nicholson, working for the U.S. National Geographic Society, develops about this time a lightweight underwater robot camera that can take sharp photographs at depths up to about 150 m (500 ft).

The Postscript system of desktop publishing is introduced. *See also* 1975 COMM; 1985 COMM.

Martine Kempf [b. Strasbourg, France] develops voice recognition software for use on an Apple computer; this software will lead to the Kata-lavox, a device for operating voice-activated wheelchairs and magnifying devices used in microsurgery. *See also* 1980 COMM; 1983 COMM.

Computers

John F. Shoch and Jon A. Hupp of Xerox Palo Alto Research Center in California develop the first computer "worm" program, a program that runs in segments on several computers, an anticipation of the first parallel processing programs. *See also* 1965 COMP.

Joe Condon and Ken Thompson's dedicated computer for playing chess, BELLE, contains 1700 chips and evaluates 160,000 positions per second. It rates second in speed chess at the 1982 U.S. National Open. *See also* 1974 COMP; 1989 COMP.

Only 10 months after the introduction of the IBM Personal Computer (PC), Columbia Data Products announces the first computer based on the PC that can run programs designed for the PC. Such copies are at first nicknamed clones and later come to be called IBM-compatible or PC-compatible computers. Compaq soon introduces its own "clone" of the PC. Later in the year, Compaq introduces a PC clone that is portable, unlike the PC itself. Both Compaq clones are immediate commercial successes. *See also* 1981 COMP.

Earth science

The weather pattern called El Niño — a shift in the Peru

Current away from the west coast of South America, which produces worldwide weather changes — begins strongly and continues through 1983 at the highest level known up to this time. During this period scientists recognize that the phenomenon begins with abnormally warm water in the central Pacific, a pattern called the Southern Oscillation.

John Horner discovers evidence of parental care of dinosaurs among *Maiasaura* fossils. *See also* 1926 ANTH.

Mathematics

Ronald N. Bracewell introduces an algorithm that replaces the Fourier transform. It is a fast version of the Hartley technique and is known as the Hartley transform or Hartley-Bracewell algorithm.

Medicine & health

Stanley Ben Prusiner [b. Des Moines, Iowa, May 28, 1942] isolates apparently infectious proteins that he names prions. He proposes that they cause infectious diseases called spongiform encephalopathies, such as scrapie in sheep or Creutzfeldt-Jacob disease in humans. *See also* 1966 MED; 1997 MED.

The U.S. Food and Drug Administration grants approval to Eli Lilly & Company to market human insulin produced by bacteria, called Humulin, the first commercial product of genetic engineering. *See also* 1980 MED.

The Swedish firm Kabivitrum produces synthetic growth hormone using genetically engineered bacteria. *See also* 1985 MED.

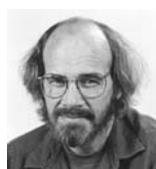
A team of doctors led by William DeVries [b. Brooklyn,

New York, December 19, 1943] implants the first Jarvik 7 artificial heart on December 2; the patient, Barney Clark, lives 112 days. *See also* 1969 MED; 1990 MED.

Physics

Alain Aspect and coworkers create the first pair of entangled polarized photons in the laboratory, thus confirming Bell's theorem that "spooky action at a distance" can exist. *See also* 1964 PHY; 1997 PHY.

Kenneth G. Wilson of the United States wins the Nobel Prize in physics for his theory of phase transitions. *See also* 1973 PHY.



John R. (Jack) Horner
[b. Shelby, Montana, June 15, 1946]

Since 1982 Horner has worked at the Museum of the Rockies in Bozeman, Montana, where he is curator of paleontology. He is particularly well known for his discovery of a colony of fossilized dinosaur nests. Some of the 75,000,000-year-old nests contained eggs, and some of the eggs contained baby dinosaurs. These were the first evidence of dinosaur colonial nesting. The plant-eating, duck-billed species was named *Maiasaura*, meaning "good mother lizard," because Horner believed the babies were fed and protected by their mothers for a period of time until they were big enough to leave the nests and forage on their own. During the 2000—01 field season at Fort Peck Reservoir in northeastern Montana, a team led by Horner discovered an unprecedented number of specimens of *Tyrannosaurus rex*.

I Tools

Applied Biosystems begins to market a version of an automated gene sequencer (based on the work of Leroy Hood [b. Missoula, Montana, October 10, 1938], that can sequence 18,000 uncorrected bases a day, compared with perhaps several hundred bases a year by hand in the 1970s. *See also* 1976 BIO; 1984 BIO.

→ Transportation

Soviet cosmonauts Anatoly Berezovoy and Valentin Lebedev begin a 211-day *Soyuz T 5* mission to the first flight space station, *Salyut 7*, on May 13. The *Salyut* space station is equipped to measure body functions. Cosmonauts aboard *Salyut 7* place *Iskra 2*, an amateur radio satellite, in orbit — the first launch of a satellite from an orbiting space station. A Soviet/French team consisting of Vladimir Dzhanibekov, Jean-Loup Chrétien, and Aleksandr Ivanchenkov begin the *Soyuz T 6* mission to *Salyut 7* on June 24. Cosmonauts Leonid I. Popov, Svetlana Savitskaya (the second Soviet woman in space), and Alexander Serebrov are launched on the *Soyuz T 7* mission to *Salyut 7* on August 16.

U.S. astronauts Jack R. Lousma and C. Gordon Fullerton are launched on the third mission of the space shuttle *Columbia* on March 22. The trip lasts eight days and the payload includes space science experiments. On June 27 Thomas K. Mattingly II and Henry Hartsfield, Jr. begin the fourth mission of the space shuttle *Columbia*, and the first to land on a hard surface. The fifth flight of space shuttle *Columbia*, launched on

November 11, is its first operational mission. The first four-man crew consists of Vance D. Brand, Robert F. Overmyer, Joseph P. Allen, and William B. Lenoir. The first deployments of satellites from the shuttle are completed.

1983

◀ Anthropology

In Kenya, Dr. Meave Epps Leakey [b. 1942] finds a fossil jaw tentatively dated between 16,000,000 and 18,000,000 years ago and identified as *Sivapithecus*, an ape that later will be identified as the ancestor of the orangutan. *See also* 1993 ANTH.

▲ Archaeology

Peat cutters in the Lindow Moss in Cheshire, England, find what appears to be a woman's skull. Although a local man confesses that it is the skull of his murdered wife, the bone will later be dated as at least 1700 years old. *See also* 1984 ARCH.

Scientists develop a method for dating ancient objects based on chemical changes in obsidian. *See also* 1957 EAR.

★ Astronomy

The *Infrared Astronomical Satellite (IRAS)*, designed to detect infrared radiation from objects in space, is launched on January 25. It completes its mission in November. In the course of its mission, it will discover evidence of planet formation around stars outside the solar system. *See also* 1995 AST.

Andrei Linde develops a model for a chaotic inflationary universe (different from his new inflationary universe

of the previous year). *See also* 1981 AST.

❖ Biology

In April Kary Banks Mullis [b. Lenoir, North Carolina, December 28, 1944] conceives of the idea of polymerase chain reaction (PCR), a method of multiplying copies of parts of a DNA molecule. It will become the basis of genetic fingerprinting and one of the key tools for all sorts of work with genetics. *See also* 1984 BIO; 1993 CHEM.

Andrew W. Murray and Jack Szostak, working with yeast, create the first artificial chromosome. *See also* 1997 BIO.

Walter Jakob Gehring [b.

Zürich, Switzerland, March 20, 1939] and coworkers discover the homeobox, a common sequence of genes in a wide variety of organisms that directs development of the organism; all of the organisms containing the homeobox — insects, annelid worms, vertebrates, and so forth — are segmented, suggesting that the homeobox directs segmentation.

Barbara McClintock of the United States wins the Nobel Prize in physiology or medicine for her discovery of mobile genes in the chromosomes of corn. *See also* 1950 BIO.

▷ Chemistry

Henry Taube of the United States — although Canada considers him to be the first Canadian to win a Nobel — wins the Nobel Prize in chemistry for new discoveries in the basic mechanism of chemical reactions. *See also* 1953 CHEM.

◀ Communication

The first regular U.S. cellular telephone system goes into operation. By 1987 there will

be 312 cellular systems operating in 205 cities. *See also* 1979 COMM; 1992 COMM.

Kurzweil Music Systems introduces a portable, digital, music keyboard that can store the sounds of 30 different musical instruments. *See also* 1969 COMM.

On October 20 an international agreement goes into effect that defines the meter as the distance that light travels through a vacuum in 1/299,792,458 second; thus, the speed of light is *exactly* 299,792,458 m per second. *See also* 1967 PHY; 1990 PHY.

▀ Computers

Apple's Lisa computer brings the mouse and pull-down menus to the personal computer. A computer mouse is a device that moves the cursor on the screen as a result of moving the mouse on a hard surface. Pressing a button on the mouse sends a command to the computer, depending on where the cursor is located. Pull-down menus are choices that appear when the menu is summoned with a push of the mouse button. Lisa is too expensive and clumsy to be commercially successful, but it leads to the very popular Macintosh, which has the same features. *See also* 1968 COMM.

Fred Cohen coins the term "computer virus" to describe programs that can insert copies of themselves into other programs. He is also the first to write such a program as part of his research into computer security. *See also* 1988 COMP.

Radio Shack introduces Model 100, the first version of a computer small enough to hold on one's lap. The display is an 8-row, 40-column LCD.

Humans learn to copy DNA

Humans, like all other living organisms, regularly make single copies of DNA within their cells so that growth and reproduction can occur by cell division. One of the key discoveries in biotechnology, however, is the method of making multiple copies of DNA in a laboratory flask. Along with genetic engineering, the process of copying DNA has revolutionized the way research in biology and medicine is conducted. Surprisingly, the method was developed by a totally unlikely person.

Kary Mullis seemed to be one of those California types, Berkeley variety. With a PhD in biochemistry from Berkeley, he drifted for seven years from job to job, not always directly connected with biochemistry. In 1979, however, he began a close relationship with one of the rising California biotechnology giants, the Cetus Corporation. The lab specialized in developing probes to recognize specific parts of a DNA molecule. These probes are used to locate genes, which are, of course, parts of a DNA molecule. In Mullis's original job, he had to use a probe to locate a matching fragment among millions of DNA pieces in a solution. Although hired by Cetus as a technician, Mullis found ways to automate his work and soon was running the laboratory where he had been assigned.

In April, 1983 Mullis thought of a way to make his job much simpler still. Instead of using a probe to pick out a single strand of DNA, he could use the probe to make multiple copies of any part of a DNA molecule. When he got back to Cetus to test the idea, it worked on the first try. Still, it took four years after that to resolve details.

The new process, called PCR for polymerase chain reaction, quickly became applied to sensitive genetic tests, including the process known as DNA fingerprinting. It also has been used to

study ancient forms of life from bits of DNA found in fossils. PCR was essential for the Human Genome Project and in mapping the many other genomes of organisms. Even more quickly than genetic engineering and monoclonal antibodies have done, PCR has become one of the pillars of the revolution in biotechnology.

PCR works in part by manipulating the copying process built into DNA. The signals for starting and stopping reproduction of a gene or another line of DNA code were discovered while deciphering the entire genetic code in the 1960s. In PCR such a start code is attached to the part of a strand of the DNA double helix for the line of code that is to be duplicated. The modified line is put into a solution where it can react with a good supply of the four bases (chemicals often known by their initials — A, C, G, and T) that make up the code. The line to be copied is usually less than 3000 pairs of these bases. An enzyme, DNA polymerase, which causes the line of code to be copied, is also added to the solution. The start code is copied along with the rest of the line. Thus, as soon as the first copy is made, there are two copies in the solution, each of which has the instructions and ability to copy itself. In this way, four copies result, each with the ability to double by copying. After ten such passes, there are over a thousand copies and after 20 passes there are over a million copies. PCR is also known as gene amplification.

The whole process requires warm temperatures to separate the strands of the helix and cooler ones for the actual copying process. In the original version of PCR, the DNA polymerase was degraded by the heat, which meant that more enzyme had to be added after each copying cycle. In 1987 a new version of the DNA polymerase enzyme was found; it copies at the higher temperatures needed for strand separation. This enzyme is used by bacteria that normally live in hot springs in Yellowstone National Park. With the bacterial enzyme surviving the process, it became possible to develop a machine that automated the entire chemistry.

The computer runs for several hours on four AA batteries. It is much less sophisticated than the personal computers available in desktop versions.

The British firm Immos develops the transputer, a parallel computer in which several processors work simultaneously, each on a different part of a problem, thus speeding up processing considerably. *See also* 1965 COMP; 1985 COMP.

IBM's PC-XT, introduced in February, is the first personal computer with a hard-disk

drive built into it. The hard disk is a memory device capable of storing a large amount of information even when the machine is turned off (thus replacing many floppy diskettes). In the first XT's, the hard disk contains 10 megabytes of information. *See also* 1981 COMP.

Construction

The world's largest thin-arch dam — 209 m (685 ft) high and 1265 m (4150 ft) long — spans the American River near Auburn, California. *See also* 1979 CONS.

Ecology & the environment

Carl Sagan and an interdisciplinary group of scientists publish a report on the consequences of nuclear war, showing that even a limited nuclear war would have grave consequences; smoke and dust injected into the atmosphere would result in severe climatic changes (termed a nuclear winter) that would destroy most living creatures. Their work is based on a theory explaining the K-T mass extinction. *See also* 1980 EAR.

Medicine & health

Luc Montagnier [b. Chabris, France, August 18, 1932] isolates the first virus known to cause AIDS, which he calls LAV (for lymphadenopathy-associated virus). The virus will become known as human immunodeficiency virus, type 1, or HIV-1, in 1987, after a compromise between French and American teams that both investigated the virus and after the discovery of a second virus, HIV-2, by Montagnier's team. *See also* 1984 MED.

Barry J. Marshall [b. Kalgoorlie, Australia, September 30, 1951] and J. Robin Warren [b. Adelaide, Australia, June 11, 1937] at Royal Perth Hospital in Australia discover that a bacterium — initially identified as *Campylobacter pylori* but later known as *Helicobacter pylori* — causes gastritis and may cause ulcers of the stomach and small intestine. Later research will show that the bacterium is definitely implicated not only in ulcers but also in stomach cancer.

Marc Cantin, Jacques Genest, and coworkers locate in June the hormone produced by the

heart that regulates blood pressure. It is synthesized two months later by a group headed by Ruth F. Nutt. *See also* 1981 MED.

James F. Gusella finds a gene marker for Huntington's disease. At Oxford Kay Davies and Robert Williamson find a gene marker for Duchenne muscular dystrophy. *See also* 1978 MED; 1986 MED.

Fernand Daffos is the first doctor to use fetal blood taken by a needle through the umbilical cord for diagnosis of disease in the fetus. *See also* 1952 MED; 1984 MED.

John Buster and Maria Bustillo of the Harbor-UCLA Medical Center in Torrance, California, perform the first successful human embryo transfers. *See also* 1951 FOOD.

The immunosuppressant cyclosporine is approved by the U.S. Food and Drug Administration, making transplants of organs much safer than previously. *See also* 1953 MED; 1963 MED.

⌘ Physics

A team headed by Carlo Rubbia [b. Gorizia, Italy, March 31, 1934] at CERN discovers the charged W particles and

the neutral Z particle, predicted carriers of the weak force according to the electroweak theory that unifies the weak force with electric charge. This, along with the earlier discovery of neutral currents, confirms the electroweak theory. *See also* 1967 PHY; 1984 PHY.

William Fowler and Subrahmanyam Chandrasekhar [b. Lahore, India (Pakistan), October 19, 1910, d. Chicago, August 1995] of the United States win the Nobel Prize in physics for their investigations into the aging and ultimate collapse of stars.

AIDS

In the late 1970s, physicians in New York and San Francisco began to encounter some unusual cases of fungal infections and a rare cancer called Kaposi's sarcoma. When the Centers for Disease Control in Atlanta, Georgia, were brought in to study the situation in 1980, they found some 500 cases of a mysterious disease that knocked out the immune system. Because more than 400 of the first known cases were among homosexual men, the newly discovered immune disorder was at first termed gay-related immune disorder, but in 1981 the name was changed to acquired immune deficiency syndrome, or AIDS.

By now, everyone knows about AIDS, but it was still fairly obscure in the early 1980s. In August 1985, however, the motion picture star Rock Hudson was revealed to have the disease (he died shortly afterward). Suddenly, it was clear to the American public that AIDS was a very serious problem. Furthermore, people soon learned that the syndrome extended far beyond the male homosexual community. Women, especially in Africa, developed the syndrome as did their children.

AIDS had already been shown to be the result of an infectious disease by 1985, caused by a virus now known as HIV (there are two forms, HIV-1 and HIV-2, with HIV-1 most common). The virus spreads exclusively by infected body fluids — blood, semen, mother's milk. Before recognition of the virus by Luc Montagnier in 1983 and development of a blood test by Robert Gallo in 1984, HIV was being transmitted by blood transfusions and even by clotting factors used to ameliorate hemophilia. Not very much

blood is needed to carry the virus from one person to another. A drug addict can be infected by reusing an unsterilized needle after an infected addict's injection. Needle reuse became the most significant mode of transmission in the United States, although sexual transmission also remained very important and has been the main source of infection around the world. Infected mothers can also pass the disease on to newborn babies, either during birth or while nursing.

HIV kills mainly by destroying the immune system, that part of the body designed to protect against viruses and other invaders. People do not die directly from HIV toxins or HIV-induced cell death, but from the many illnesses that infect a person with impaired immunity. There is no known cure for HIV infection, although various combinations of medicines have greatly slowed the progress of the disease. The medicines have proven most helpful in the United States and other Western countries where people can afford them. In Western nations, more than 1,000,000 people live with HIV infection. But HIV infection has often gone untreated in less developed regions, especially Africa, leading to AIDS and death.

In the United States about half a million persons have died of AIDS since 1981, but for the entire world the number of deaths exceeds 25,000,000. In Africa, however, nearly 30,000,000 persons are thought to be infected with HIV (out of 42,000,000 worldwide). Few with HIV in poor nations will escape AIDS unless there are major changes in the way that medicine is made available. Several efforts were in place to make such changes by early in the 21st century.

I Tools

U.S. president Ronald Reagan [b. Tampico, Illinois, February 6, 1911] announces the start of a Strategic Defense Initiative (SDI), soon known as the Star Wars program. The plan is to build a satellite-based system for intercepting intercontinental ballistic missiles using interceptor missiles and laser beams. *See also* 1944 TRAN.

On July 3 the Tevatron particle accelerator at Fermilab is tested for the first time and immediately sets a new record of 412 GeV (billion electron volts) for energy produced by collisions of subatomic particles. *See also* 1972 TOOL.

✈ Transportation

The second U.S. space shuttle, *Challenger*, is successfully launched on April 4. Astronauts Paul J. Weitz, Karol J. Bobko, Donald H. Peterson, and F. Story Musgrave form the crew of the first *Challenger* mission. A TDRS tracking satellite is deployed and the first shuttle EVA is completed. The first five-person crew for a space shuttle, consisting of Sally K. Ride, the first U.S. woman in space, Robert L. Crippen, Frederick H. Hauck, John M. Fabian, and Norman E. Thagard, begin a second *Challenger* mission on June 18. The Remote Manipulating Structure ("Arm") is used to deploy and retrieve a satellite for the first time. The first night launch of a *Challenger* mission begins August 30 with a crew of Richard H. Truly, Daniel Brandenstein, William Thornton, Guion S. Bluford, Jr. (the first African-American in space), and Dale Gardner complete. The crew launches a weather/communications satellite for India.

U.S. astronauts John Young, Brewster Shaw, Jr., Robert Parker, Owen Garriott, Byron Lichtenberg, and Ulf Merbold are launched on a *Columbia* mission on November 28. The shuttle carries a laboratory called Spacelab, and the crew performs numerous experiments in astronomy and medicine.

Soviet cosmonauts Vladimir B. Titov, Gennadi M. Strekalov, and Aleksandr A. Serebrov begin the *Soyuz T 8* mission on April 20 but fail in a planned rendezvous with *Salyut 7*. On June 27 Vladimir Lyakhov and Aleksandr Alexandrov begin a 150-day *Soyuz T 9* mission. They spend 49 days in *Salyut 7*, but *Soyuz T 10* fails in a relief mission. A fire starts just as the launch begins and the flight is aborted, although the vehicle travels several kilometers. The crew escapes safely.

1984

◆ Anthropology

Charles Sibley and Jon Ahlquist use studies of DNA to explore the relationships among humans and the great apes; they conclude that humans are more closely related to chimpanzees than either humans or chimpanzees are to other great apes, and that humans and apes diverged about 5,000,000 to 6,000,000 million years ago. *See also* 1981 BIO; 1985 BIO.

■ Archaeology

Michael G. L. Baillie and coworkers establish an unbroken tree-ring chronology based on Irish oak trees that extends to 7272 years back in time.

Many previously unknown tombs turn up at the excava-

tions by Sayed Tewfik and coworkers at the Necropolis at Sakkara in Egypt. These tombs belong to high officials of Ramses II, perhaps the most powerful pharaoh. *See also* 1987 ARCH.

Richard E.W. Adams uncovers in a jungle in Guatemala the first unlooted Maya tomb found since the early 1960s; it had been sealed effectively in the fifth century CE. *See also* 1987 ARCH.

On August 1 peat cutter Andy Mould, working in the Lindow Moss near Cheshire, England, discovers Lindow Man, a 2000-year-old body preserved in a peat bog. Later researchers will come to believe that Lindow Man was a Druid who was killed in a ritual involving a burned barley cake called a bannock. The priest who got the burned piece of bannock was sacrificed to the Celtic gods. Freeze-dried Lindow Man now rests in the British Museum. *See also* 1983 ARCH.

A storm in the Mediterranean uncovers the underwater site of an 8000-year-old settlement, now known as Atlit-Yam, off the coastal town of Atlit, Israel.

★ Astronomy

Bradford A. Smith of the University of Arizona and Richard J. Terrile of NASA photograph a dust region thought to be a planetary system forming around the star Beta Pictoris. *See also* 1987 AST.

André Brahic, William B. Hubbard, Harold J. Reitsema, and coworkers discover a partial ring around the planet Neptune. They are watching Neptune during an occultation of a star — that is, the

planet passes between Earth and the star, hiding the star. The star blinks on one side of Neptune, implying a narrow ring, but fails to blink on the other side, implying a gap in the ring. J.C. Bhattacharyya and his group at the Indian Institute of Astrophysics in Bangalore and Uttar Pradesh State Observatory at Naini Tal discover two more rings of Saturn during the occultation. *See also* 1989 AST.

Astronomers from Cambridge University mask parts of a 224-cm (88-in.) reflector in Hawaii to create the first astronomical measurements using interferometry. *See also* 1974 AST; 1988 AST.

On December 15 *Vega 1*, the first Soviet mission to study Comet Halley, is launched, followed on December 21 by *Vega 2*, also to study Comet Halley. Both probes release a balloon probe at Venus on their way to the comet.

↗ Biology

Robert Sinsheimer, chancellor of the University of California at Santa Cruz, proposes mapping all of the genes in a human being, a suggestion that will lead to the Human Genome Project. *See also* 1982 BIO; 1988 BIO.

Archie Carr [b. Mobile, Alabama, 1910, d. Micanopy, Florida, May 21, 1987] discovers where at least some sea turtles live between the time they hatch and their reappearance as young adults. The young turtles make their way to beds of floating seaweed, where they live on other small animals that make their homes in the seaweed patches.

Independently of Thomas Cech, Sidney Altman discov-

ers catalytic RNA. *See also* 1982 BIO; 1989 BIO.

The genomes of the virus that causes hepatitis B and one of the common cold viruses (human rhinovirus type 14) are sequenced. *See also* 1981 BIO; 1985 BIO.

Steen A. Willadsen [b. Copenhagen, Denmark, 1944] successfully clones sheep, producing genetically identical sheep by separating an embryo into separate cells and introducing the cell nucleus into sheep ova that have had their nuclei removed. The altered eggs are then implanted in female sheep for development into fetuses and birth. *See also* 1970 BIO; 1997 BIO.

Allan Wilson and Russell Higuchi of the University of California at Berkeley become the first to clone genes from an extinct species. They clone genes from a preserved skin of a quagga, a form of zebra that had been extinct for a hundred years. *See also* 1985 ARCH.

Alec Jeffreys and coworkers at the University of Leicester, United Kingdom, develop the method of genetic fingerprinting, the identification of certain core sequences of DNA unique to each person. This method can be used not only for identifying individuals but also for establishing family relationships. The technique will become vastly more useful after 1987 when combined with use of the polymerase chain reaction (PCR) to amplify genetic material recovered in very small amounts. *See also* 1901 BIO; 1987 BIO.

Naturalist Katy Payne [b. 1937] discovers that elephants use sounds too low for humans to hear for communication.

Chemistry

Peter Armbruster [b. Dachau (Bavaria), July 25, 1931] and Gottfried Munzenberg announce the creation of three atoms of element 108, which later will be named hassium (Hs).

R. Bruce Merrifield of the United States wins the Nobel Prize in chemistry for his discovery of a method for creating peptides and proteins. *See also* 1969 BIO.

Communication

Paul Mockapetris from the Information Sciences Institute at the University of Southern California originates the domain name system for the Internet. The suffixes .com, .org, .edu, and .gov, called domain names, are used by the Internet system as part of most uniform resource locators (URLs), the addresses of the Internet. *See also* 1992 COMM.

Philips and Sony introduce the CD-ROM (compact disk read-only memory), an optical disk that can store very large amounts of digital data — essentially a CD for personal computers. *See also* 1982 COMM.

Digital Productions produces scenes of battles in space created entirely by computer for the film *The Last Starfighter*; to create the 25 minutes of space images, a 400 megaflop supercomputer runs day and night for a month.

Bill Atkinson of Apple develops MacPaint, a revolutionary graphics package that makes the drawing of pictures that appear on a computer monitor (and then mailing or printing of them) possible.

Computers

A study at the Technical University of Berlin is the first discussion of computer viruses, including Friday 13, Holland Girl, Trojan Horse, and Christmas Tree. In subsequent years computer viruses become a serious problem, spreading through exchanged diskettes and computer networks. *See also* 1983 COMM; 1988 COMP.

Apple introduces the Macintosh, a graphics-based microcomputer using icons and a mouse and an intuitive user interface derived from the Lisa computer. *See also* 1983 COMP; 1985 COMP.

Earth science

Soviet researchers drill to a depth of 12 km (7.5 mi) and reach Earth's lower crust in the Kola Hole. *See also* 1964 EAR.

Carbon dioxide from Lake Monoun in Cameroon kills 37 people. The gas builds up in lower levels of the lake, probably as a result of volcanic activity. When the density of a lower level becomes less than that of levels above it, the lake waters "overturn," releasing large amounts of gas. *See also* 1986 EAR.

Hou Xianguang discovers the Chengjiang Cambrian fossil site in southern China, a stratum rich in well-preserved animals, including soft bodies, from about 530,000,000 years ago.

Ecology & the environment

In Bhopal, India, more than 2000 persons die and thousands more are injured by toxic gas from an accident at an

American-owned Union Carbide plant. *See also* 1976 ECOL.

The U.S. government takes steps toward a complete ban on leaded gasoline in order to reduce lead concentrations in the lower atmosphere. *See also* 1978 ECOL; 1986 ECOL.

Electronics

IBM introduces a megabit RAM memory chip with four times the memory of earlier chips. *See also* 1981 ELEC; 1987 ELEC.

Materials

Dany Schechtman, Ilan Blech, Denis Gratias, and John W. Cahn, workers at the U.S. National Bureau of Standards, find the first quasicrystal, an aluminum alloy that appears to be a crystal but that has a "quasiperiodic" pattern of repetition related to Penrose tiling not found in nature. The alloy of aluminum and manganese shows fivefold symmetry. *See also* 1974 MATH.

Medicine & health

Robert C. Gallo [b. Waterbury, Connecticut, March 23, 1937] develops a blood test for the virus that causes AIDS, a virus he calls HTLV-2 (now known as HIV-1), previously found by Luc Montagnier and first named LAV. *See also* 1983 MED; 1987 MED.

The American Heart Association lists smoking as a risk factor for strokes for the first time. *See also* 1988 MED.

Surgeon William H. Clewell of the University of Colorado Health Sciences Center at Denver performs the first successful surgery on a fetus before birth. *See also* 1983 MED; 1999 MED.

The first xenotransplant, the transplant of a baboon heart into a baby, is performed at Loma Linda Medical Center in California. The baby survives 20 days.

The hormone produced by the heart, discovered by Adolpho de Bold, is isolated and analyzed by de Bold and several other teams. One result of all the activity is that the hormone is variously named auriculin, atriopeptin, and cardionarin, leading to its simply being called the “heart hormone.” See also 1983 MED.

The first human baby is born from a frozen embryo in Melbourne, Australia. See also 1973 FOOD.

Norman Rosenthal and coworkers identify seasonal affective disorder (SAD), a form of depression that occurs each winter in susceptible individuals. They link it to shorter periods of light and suggest using bright artificial lights in the early evening and early morning to treat the disorder.

César Milstein of Britain, Georges Köhler of West Germany, and Niels K. Jerne [b. London, December 23, 1911, d. Castillon-du-Gard, France, October 7, 1994] of Denmark share the Nobel Prize for physiology or medicine, Milstein and Köhler for their research on monoclonal antibodies, and Jerne for his studies of the immune system. See also 1975 MED.

❖ Physics

Michael Green and John Schwarz show that superstring theory is free from quantum anomalies if the space-time dimension is 10 and the quantum gauge symmetry is the mathematical group SO(32)

or $E_8 \times E_8$. This breakthrough makes superstring theory suddenly very popular with theoretical particle physicists. See also 1974 PHY; 1995 PHY.

Carlo Rubbia of Italy and Simon van der Meer [b. The Hague, Netherlands, November 24, 1925] of the Netherlands win the Nobel Prize in physics for their discovery of the W and Z particles. See also 1983 PHY.

I Tools

Dennis L. Matthews builds the first successful X-ray laser. The X rays are produced in a plasma created by the vaporization of selenium by a laser. Collisions between selenium atoms and free electrons excite the selenium atoms to sufficiently high levels so that they emit soft X rays. See also 1980 TOOL; 1985 TOOL.

Jean-Marc Halbout and Daniel Grischkowsky at IBM develop a laser that creates pulses of 12 femtoseconds (12 quadrillionths of a second). See also 1980 TOOL.

→ Transportation

On February 3 Vance Brand, Bruce McCandless II, Robert Stewart, Ronald McNair, and Robert Gibson are launched on the space shuttle *Challenger*. During the mission, jet-propelled backpacks carry two astronauts on the first untethered space walks. Two satellites (Western Union and Indone-sian) are lost, and the first landing at Kennedy Space Center is completed. On April 6 a second *Challenger* mission with a five-person crew is launched; it carries Robert Crippen, Richard Scobee, Terry Hart, George Nelson, and James van Hoften. The Long Duration Exposure Facility is

deployed, and the *Solar Max* satellite is snared and its attitude control system repaired. The third *Challenger* mission of the year is launched on October 5. The seven-person crew consists of Robert Crippen, David Leestma, Jon McBride, Sally Ride, Paul Scully-Power, Kathryn Sullivan, and Marc Garneau, the first Canadian astronaut. *Challenger* deploys the *Earth Radiation Budget Satellite*, monitors land formations, ocean currents, and wind patterns, and uses the Sir-B radar system to see beneath the surface of desert sand.

On August 30 the first mission of the third space shuttle, *Discovery*, begins with a six-person crew — Henry Hartsfield, Jr., Michael Coats, Steven Hawley, Judith Resnick, Richard Mullane, and Charles Walker. It deploys three satellites and tests a solar sail.

On November 8 the second *Discovery* mission is launched with a five-person crew: Joseph Allen, Anna Fisher, Dale Gardner, Frederick Hauck, and David Walker. *Discovery* salvages two inoperative satellites and returns them to Earth for repair.

On February 8 three Soviet cosmonauts, Oleg Atkov, Leonid Kizim, and Vladimir Solovyov, are launched on the *Soyuz T 10B* mission, which replaces the failed *Soyuz T 10* mission. They travel to the *Salyut 7* space station to repair the propulsion system, and set a new crew duration in space record at 237 days. Yuri Malyshev, Gennady Strekalov, and Rakesh Sharma, the first Indian cosmonaut, begin the *Soyuz T 11* mission on April 2. The craft docks with *Salyut 7*. Vladimir Dzhanibekov, Svet-

lana Savitskaya, and Igor Volk begin the *Soyuz T 12* mission on July 18. Savitskaya becomes the first woman to walk in space.

Robert Forward at Hughes Aircraft proposes using a sail propelled by a laser for space travel. The laser, placed in Earth orbit or on the surface of the Moon, would focus on the sail as the spaceship is propelled even as far as nearby stars.

1985

◀ Anthropology

Alan Walker finds near Lake Turkana, in northern Kenya, a skull of an early hominid (KNM-WT 17000, a.k.a. the Black Skull) classified as *Paranthropus (Australopithecus) aethiopicus*.

▲ Archaeology

Swante Pääbo [b. Stockholm, Sweden, 1955] extracts and characterizes DNA from the skin of an Egyptian mummy who died about 4000 BCE. See also 1985 BIO.

★ Astronomy

Vera Rubin and coworkers report that 60 galaxies that they have studied exhibit patterns of rotation that can only be explained if each is embedded in a much larger amount of unobserved dark matter. See also 1973 AST.

Neil Turok suggests that groups of galaxies called Abell clusters appear to have formed as a result of cosmic strings, long, thin remnants of the original energy of the big bang that have persisted to this day. See also 1976 AST.

Construction of the world’s

Missing mass

In the 1920s scientists discovered that the universe is expanding. Alexander Friedmann had proved that Einstein's general theory of relativity required space to spread out with time, and Edwin Hubble had observed that it actually did expand. Friedmann's equations, however, predicted three possible types of expansion. In two of them space becomes forever larger in slightly different ways. In the third expansion gradually slows, stops, and finally contracts. That last universe is called "closed." The parameter that makes the difference between the three situations is the amount of mass in the universe. Too much mass and the universe collapses. Too little mass and the expansion becomes runaway, virtually blowing the universe apart. When, like the Baby Bear's porridge, the mass of the universe is just right, the expansion continues forever but gradually slows down, keeping the universe much as we know it today. This is called the "flat universe."

Astronomers since World War II have been working on the problem of determining the amount of mass. Most astronomers prefer a universe that collapses or is flat. But when the amount of mass is calculated from known observable galaxies and dust, it is far too small. If these calculations are correct, the universe will undergo runaway expansion.

There is, however, mass in the universe that we cannot observe. Vera Rubin has shown that galaxies rotate too quickly near their edges. According to the laws of gravity and rotation, if the observable boundary of a galaxy were the real edge, rotational speed would be reduced in parts of the galaxy away from the center. Since Rubin's observations establish that this is not the case, there must be great clouds of unobserved mass in which each galaxy is embedded. She could even calculate how much unobserved mass there is for that galaxy.

But the newly found mass in galaxies still is not enough by a large margin to close or at least flatten the universe. The inflationary universe of Alan Guth, first conceived of in 1979 and improved on by other physicists since, made the task a little easi-

er because their predicted universe needed slightly less mass to close or flatten it — but still a lot more than anyone could find. In fact, a recent effort (in 2003) to determine the proportions of missing mass to observable mass found nearly six times as much unseen as seen. Astronomers and physicists have postulated many entities that could provide the missing mass. Astronomers have contributed brown dwarfs (objects in size and energy between a planet and a star) and black holes. But physicists have provided most of the new ideas, suggesting mass that cannot be observed at all (except for gravitational effects).

For example, the universe is presumed to be filled with nearly undetectable neutrinos that are now known to have a small mass each. Although the exact amount of mass has been hard to pin down, neutrinos are not a satisfactory source of the missing mass. They move at nearly the speed of light, which prevents them from clumping together. Galaxies are thought to start when a large amount of mass accidentally forms a clump, and since we have galaxies, there should also be clumps of missing mass to initiate them.

If not neutrinos, then perhaps some undiscovered particle could provide the missing mass. Particles predicted by various physicists include magnetic monopoles, photinos, axions, gravitinos, and winos. Most of these are grouped together as WIMPS — weakly interacting massive particles — which means that they are hard to detect if present and also hard to produce in particle accelerators (since the more massive a particle is, the more energy it takes to create it).

Yet another idea from physics is the cosmic string, first proposed in 1976. A cosmic string is not a particle, but an incredibly long, skinny bit of leftover energy from the big bang. Even a couple of kilometers of a cosmic string has a mass similar to that of Earth — and some cosmic strings are expected to reach from one end of the universe to another. One of the nice things about cosmic strings as a way to supply the missing mass is that, unlike the various particles, they are in principle observable. So far, however, possible sightings have been few and not convincing.

largest telescope, Keck I, begins on Mauna Kea in Hawaii. The Keck telescope's mirror is 10 m (33 ft) in diameter, but consists of 36 hexagonal segments adjusted by a computerized adaptive optics system.

Edward F. Tedesco detects the eclipses of Pluto by its moon Charon and determines the diameter of Pluto to be less than 3000 km (1900 mi), making Pluto (not Mercury, as

previously believed) the smallest planet. *See also* 1978 AST.

Sakigake, the first Japanese mission to study Comet Halley (from far away), is launched on January 7. On July 2 *Giotto*, a joint European mission to study Comet Halley, is launched. *Giotto* passes closest to the comet of any mission, coming within 600 km (375 mi). *Suisei*, another Japanese mission to Comet

Halley, is launched on August 18. *See also* 1984 AST; 1991 AST.

Biology

The genome of HIV-1, the most common cause of AIDS, is sequenced along with that of a virus that causes cervical cancer (human papillomavirus type 16). *See also* 1984 BIO; 1987 BIO.

Charles Sibley and Jon Ahlquist use DNA studies to revise the evolutionary history

of perching birds and songbirds from Australia and New Guinea. *See also* 1981 BIO.

A semipalmated sandpiper, banded and released four days earlier in Plymouth Beach, Massachusetts, is shot in Guyana, 4500 km (2800 mi) away. The distance sets a record for a flight over water by a shorebird.

Telomerase, a protein that repairs telomeres (end units of chromosomes that shorten

with each cell division and appear to trigger aging), is discovered. *See also* 1982 BIO.

Chemistry

Herbert A. Hauptman and Jerome Karle of the United States win the Nobel Prize in chemistry for their work on equations to determine the structure of molecules. *See also* 1953 CHEM.

Communication

Paul Brainard writes Page-Maker, the first desktop publishing package developed for a microcomputer. At first it is only for the Apple Macintosh computer, but later the software will become available for PC-compatible computers also. *See also* 1982 COMM.

Randy Wigginton, Ed Ruder, and Don Breuner develop MacWrite, a word-processing program for the Macintosh computer that makes use of icons, graphic illustrations of such items as a file cabinet or a wastebasket that can be pointed at (with a mouse) to indicate operations such as saving a file or erasing one. *See also* 1978 COMM.

Computers

Microsoft develops Windows for the IBM PC, a graphics-based user interface that allows the use of an IBM PC-compatible computer in a way similar to the Macintosh. *See also* 1984 COMP.

Toshiba introduces a true laptop computer, the T1100. *See also* 1981 COMP.

The U.S. National Science Foundation sets up five national supercomputing centers, in San Diego, California, Pittsburgh, Pennsylvania, Princeton, New Jersey, Ithaca,

New York, and Champaign-Urbana, Illinois. The last is called the National Center for Supercomputing Applications (NCSA).

Cray Research introduces the Cray 2, a strongly miniaturized supercomputer ten times as powerful as the Cray 1. It contains four processors, has a 2,000,000,000-byte memory, and can perform 1,000,000,000 floating-point operations per second; later versions have 8,000,000,000-byte memories. *See also* 1976 COMP; 1989 COMP.

Thinking Machines introduces the Connection Machine, a computer with 16,384 parallel processors and a speed of 600,000,000 operations per second; at a later stage the number of processors is extended to 65,536 and its speed is 1,000,000,000 operations per second. *See also* 1983 COMP; 1991 COMP.

Earth science

The JOIDES (Joint Oceanographic Institutions Deep Earth Sampling) project to take deep cores from the seafloor begins. It discovers that no part of the ocean bottom is older than 200,000,000 years (compared with the 4,500,000,000-year-old age of Earth), another confirmation of the theory of seafloor spreading.

Peter A. Rona discovers the first deep-sea ocean vents, or hot springs, on the mid-Atlantic ridge in the Atlantic Ocean; previous vents had been found in the Red Sea and the Pacific. *See also* 1977 EAR.

Ecology & the environment

The British Antarctic Survey detects a hole in the ozone layer over Antarctica, as ozone

levels fall to their lowest amount in September. Satellite records confirm that the hole had formed for several years previously. *See also* 1978 ECOL.

The brown pelican (*Pelicanus occidentalis*) becomes the first species to be removed from the U.S. Endangered Species List. Between 1957 and 1961, DDT and other pesticides had drastically reduced the Texas population and completely eliminated the original Louisiana population, with lesser impacts occurring in other southeastern states by causing reproductive failure due to egg thinning. Elimination of long-lasting pesticides was the biggest factor in species recovery. *See also* 1987 ECOL.

Electronics

Masaki Togai and Hiroyuki Watanabe, two researchers at AT&T Bell Labs, develop a logic chip that operates on fuzzy logic. *See also* 1965 MATH; 1987 TRAN.

Intel introduces the 80386, a 32-bit microprocessor. *See also* 1978 ELEC.

Energy

The Superphénix, the world's largest fast-breeder reactor, producing 1200 megawatts of electricity, starts operating in Creys-Malville, France. Continuous technical problems will cause the reactor to be shut down for most of the time until 1992, when the French government decides to decommission the reactor indefinitely. *See also* 1979 ECOL.

Materials

Richard Erret Smalley [b. Akron, Ohio, June 6, 1943] and Harold Walter Kroto [b. Wisbech, England, October 7, 1939] discover that some car-

bon arranges itself in the form of "buckyballs," soccer-shaped molecules with 60 atoms. They call these buckminsterfullerenes after Buckminster Fuller [b. Milton, Massachusetts, July 12, 1895, d. Los Angeles, California, July 1, 1983], who developed geodesic domes of essentially the same shape. *See also* 1926 MATR; 1991 MATR.

Information about lanxides, crosses between ceramics and metals, is released for the first time when the U.S. Defense Department declassifies the three-year-old subject. *See also* 1925 MATR; 1990 MATR.

Mathematics

Hugh C. Williams and Harvey Dunbar determine that the number formed by writing 1031 "1"s in a row is prime.

Medicine & health

Luc Montagnier isolates the second AIDS virus, HIV-2. *See also* 1983 MED.

The U.S. Food and Drug Administration in October approves marketing growth hormone manufactured by bacteria, the second drug produced by genetic engineering (after human insulin) to be sold in the United States. *See also* 1982 MED.

Lasers are used in the United States for the first time to clean out clogged arteries. *See also* 1977 MED.

The U.S. Food and Drug Administration approves the implantable cardiac defibrillator, an electrical device used to prevent the heart from beating too rapidly or from fibrillating (quivering instead of beating). The device is implanted in a patient's chest where it is powered for five

years by a lithium battery. *See also* 1959 MED.

Bert L. Vallee [b. Hemer, West Germany, June 1, 1919] and coworkers find the tumor angiogenesis factor, first predicted by Judah Folkman, which stimulates the growth of new blood vessels. They rename the factor angiogenin. *See also* 1961 MED.

Michael Brown and Joseph Goldstein of the United States win the Nobel Prize in physiology or medicine for their studies in the regulation of cholesterol metabolism. *See also* 1973 MED.

❖ Physics

Klaus von Klitzing of West Germany wins the Nobel Prize in physics for the discovery of the quantized Hall effect. *See also* 1980 PHY.

I Tools

A nuclear X-ray laser explodes underground, producing X-ray radiation that is 1,000,000 times brighter than that obtained in earlier tests of similar nuclear-powered lasers. This experiment is viewed as an important step toward the "star wars" program, or SDI, although the use of lasers will later be abandoned by SDI in favor of rocket interceptors. *See also* 1984 TOOL; 1988 TOOL.

Experimentalists begin to use lasers to handle individual atoms or molecules and tiny clusters of atoms or molecules or even aggregations of some size. Light is used to exert a force because photons carry momentum. Light pressure works best when particles are already nearly motionless from really low temperatures. *See also* 1975 PHY.

Gerd Binnig, Christoph Gerber, and Calvin Quate [b. Baker, Nevada, December 7, 1923] develop the atomic force microscope (AFM). A tip made of diamond, silicon, or tungsten is moved over a surface to be investigated; the small movements of the tip caused by bumps of atoms are measured with a scanning tunneling microscope. *See also* 1981 TOOL; 1987 TOOL.

❖ Transportation

The Soviet *Soyuz T 13* mission is launched on June 6; damage to *Salyut 7*, which had suffered power failure, is successfully repaired. Three cosmonauts begin the *Soyuz T 14* mission on September 17. They take supplies to *Salyut 7*, but the mission terminates early to return Vladimir Vasyutin to Earth because he is ill.

The U.S. space shuttle *Discovery* conducts four missions this year. The first, on January 24, is a two-day "secret" military mission with a five-person crew: James Buchli, Thomas Mattingly II, Ellison Onizuka, Gary Payton, and Loren Shriver. On April 12 *Discovery* begins a six-day mission; the seven-person crew includes Karol Bobko, David Griggs, Jeffrey Hoffman, Rhea Seddon, Charles Walker, Donald Williams, and Jake Garn, the first U.S. senator in space. The June 17 launch includes a seven-person crew: Daniel Brandenstein, John Creighton, John Fabian, Shannon Lucid, Steven Nagel, Patrick Baudry of France, and Prince Sultan Salman al-Saud, the first Arab in space. On this mission four satellites are successfully launched. On August 27 *Discovery* is launched with a five-

person crew: Richard Covey, Joe Engle, William Fisher, John Lounge, and James van Hoften. Three communications satellites are deployed and the satellite *Syncom 3* is repaired.

The space shuttle *Challenger* conducts three missions. On April 29 it begins a seven-day trip with a full seven-person international crew: Frederick Gregory, Donald Lind, Robert Overmyer, Norman Thagard, William Thornton, Lodewijk van den Berg, and Taylor Wang. It carries a European Spacelab module in which the astronauts conduct 15 experiments. *Challenger* is launched again on July 29 with another seven-person crew: Loren Acton, John-David Bartoe, Roy Bridges, Jr., Anthony England, Gordon Fullerton, Karl Henize, and Story Musgrave. It carries Spacelab 2, a group of astronomical experiments. The third launch is on October 30 for another seven-day scientific mission. It carries Spacelab 1-D, scientific experiments directed by West Germany. The crew is Guion Bluford, James Buchli, Bonnie Dunbar, Henry Hartsfield, Jr., Steven Nagel, Reinhard Furrer (West Germany), Ernst Messerschmid (West Germany), and Wubbo Ockels (Netherlands).

Atlantis is launched on its maiden voyage with a five-person crew (Karol Bobko, Ronald Grabe, David Hilmers, William Pailes, and Robert Stewart) on October 4. *Atlantis* brings the U.S. space shuttle fleet up to its planned size of four. On November 26 the second mission for *Atlantis* is launched. The seven-person crew includes Mary Cleave, Bryan O'Connor, Jerry Ross, Brewster

Shaw, Jr., Sherwood Spring, Charles Walker, and Rudolfo Neri Vela, the first Mexican astronaut. Crew members work on techniques for assembling structures in space and deploy three communications satellites. *See also* 1981 TRAN.

Deep-sea explorer Robert Ballard, using *Argo*, a remote controlled robot equipped with video cameras, discovers the wreck of the *Titanic*, which sank in 1912. *See also* 1912 TRAN.

Mercedes-Benz announces that a driver's side air bag will be standard on all new models. *See also* 1974 TRAN; 1990 TRAN.

1986

◀ Anthropology

At Olduvai Gorge in Tanzania, Tim White [b. August 24, 1950] and Donald Johanson locate 302 pieces of a female *Homo habilis* 1,800,000 years old, now known as OH62. It is the first time that bones from the limbs of *H. habilis* have been found. OH62 was short, only about 1 m (3 ft) tall, giving her the nickname "dik-dik hominid" (the dik-dik is a tiny African antelope); her body was more apelike than had been expected. *See also* 1960 ANTH.

▲ Archaeology

A fisherman wading in the Acula River near Veracruz, Mexico, discovers a stone stele in the riverbed. When raised, the stele is discovered to be covered with a previously unknown form of writing, dating from the first century CE. The writing is similar to glyphs used by the Maya and other Central American groups.

Brickyard workers digging clay in Sanxingdui, Sichuan, China, uncover two pits from about 1000 BCE in which bronze, jade, and gold masks and other objects were left as sacrifices.

Harold L. Dibble invents a system based on the electronic theodolite, a surveying device that records the exact three-dimensional position of artifacts as they are found in a "dig." Combined with a computer, entire levels can be shown or graphed, saving archaeologists hours of drudgery.

★ Astronomy

A team of seven astronomers called the Seven Samurai, which includes Alan Dressler and Sandra M. Faber, discover that our galaxy, the galaxies of the local group, and other components of the local supercluster of galaxies move toward a point in the direction of the Southern Cross, called the Great Attractor. The name is coined by Dressler during a news conference to announce the discovery. *See also* 1981 AST.

The U.S. space probe *Voyager 2* passes within 82,000 km (51,000 mi) of the planet Uranus. It passes the planet and its moons at a speed of more than 51,000 km (32,000 mi) per hour, taking pictures and measurements that are radioed to Earth. Ten more satellites of Uranus are discovered, as well as much new basic information about the system. *See also* 1981 AST.

Biology

Arthur Ashkin [b. September 2, 1922] and his colleagues trap individual living bacteria and particles of DNA using refraction and the radiation

pressure of a laser, allowing new methods for observing them and manipulating them. *See also* 1985 PHY.

On May 29 Agracetus, a biotechnology company in Wisconsin, conducts the first field trials of genetically engineered organisms, genetically altered tobacco. *See also* 1973 BIO.

The U.S. Department of Agriculture grants the Biologics Corporation of Omaha, Nebraska, the world's first license to market a living organism produced by genetic engineering, a virus used as a vaccine to prevent a herpes disease in swine. *See also* 1973 BIO.

Richard Morris, Gary Lynch, Michel Baudry, and coworkers show that by blocking NMDA (N-methyl-D-aspartate) receptors in the brain they can interfere with learning in rats. NMDA receptors, when stimulated by an electrical charge and the neurotransmitter glutamate, cause calcium ions to enter nerve cells. *See also* 1999 BIO.

Rita Levi-Montalcini [b. Turin, Italy, April 22, 1909] of Italy and Stanley Cohen of the United States win the Nobel Prize in physiology or medicine for their studies of the mechanisms of cell and organ growth. *See also* 1973 BIO.

Chemistry

Americans Dudley R. Herschbach and Yuan T. Lee, inventors of the crossed-beam molecular technique, and Canadian John C. Polanyi, inventor of chemiluminescence as a way of studying chemical reactions and bonds, win the Nobel Prize for chemistry. *See also* 1972 CHEM; 1967 CHEM.

Communication

On February 21 France launches SPOT, a satellite designed to photograph surface details of Earth as small as 9 m (30 ft) across. *See also* 1972 EAR.

In Europe, FM radio stations begin to utilize the radio data system (RDS) to transmit digital data via the subcarrier signal of FM. RDS can be used to transmit messages that appear on a small display screen attached to suitably equipped radios or for other purposes. *See also* 1992 COMM.

The first DAT (digital audio tape) recorders are demonstrated in Japan. *See also* 1982 COMM.

Terrence J. Sejnowski at Johns Hopkins in Baltimore develops a neural network computer that can learn to read a text out loud without knowing any pronunciation rules. *See also* 1980 COMM.

Computers

Compaq leaps past IBM by introducing the DeskPro, a computer using an advanced 32-bit microprocessor, the Intel 80386. DeskPro can run software three times faster than the fastest 16-bit computers, such as the IBM and its clones. *See also* 1985 COMP.

David Miller [b. Hamilton, Scotland, February 19, 1954] develops a tiny optical switch that later becomes the basis of the first optical computer. *See also* 1990 ELEC.

Construction

The Annacis Bridge in Canada is completed using the cable-stayed design, a method involving a deck supported by cables strung from isolated towers (as opposed to a suspension bridge in which the

cables are from strung from another cable between towers); at 465 m (1525 ft), its main span is the longest to date for the cable-stayed design. *See also* 1991 CONS.

Earth science

In August oceanographers discover a vast plume of hot water rising off the Juan de Fuca Ridge in the Pacific; the plume is thought to have been caused by a vent in the ocean's floor where two tectonic plates are moving apart. *See also* 1965 EAR; 1990 EAR.

Lake Nyos in Cameroon emits a gas that kills about 1750 people and much of the livestock around the lake. Later, investigators decide that the gas was largely carbon dioxide released in an underwater eruption of the volcano that formed the lake, or possibly caused by turnover of the lake waters. *See also* 1984 EAR.

A miner in the La Toca amber mine in the Dominican Republic finds a complete frog, 35,000,000 to 40,000,000 years old, preserved as a fossil in amber.

Ecology & the environment

Chernobyl nuclear reactor number 4, near Kiev, U.S.S.R., explodes at 1:23 a.m. local time on April 26, leading to a catastrophic release of radioactivity that kills 31 people within a few weeks and forces the mass evacuation of all families within 30 km (18.6 mi) for an indefinite period. Later studies will show a higher death rate from thyroid cancer in the region as well. *See also* 1957 ECOL.

A worldwide ban on whaling, with limited exceptions for traditional societies, begins by

international agreement. *See also* 1977 ECOL.

All the known black-footed ferrets in the wild are captured and put into a captive breeding program after canine distemper kills most of the known population. *See also* 1981 ECOL.

The U.S. government sets lower standards for the permissible amount of lead in air and bans the use of solder containing lead. *See also* 1984 ECOL; 1991 ECOL.

❖ Energy

The experimental laser fusion device Nova at Lawrence Livermore National Laboratory (LLNL) creates the first fusion reaction induced by a laser. Ten laser beams that deliver total energy of 100 trillion watts during one-billionth of a second converge on a hydrogen-filled glass sphere. A small number of hydrogen nuclei fuse into helium nuclei. *See also* 1952 TOOL; 2003 ENER.

The giant Guri Dam (a.k.a. Raul Leoni Dam) is built in Venezuela to supply 100,000 megawatts of power to that country — the world's largest hydroelectric power source of its time. *See also* 1895 ENER.

Los Alamos National Laboratory in the United States uses a two-well system to produce geothermal power; the 4-km (2.5-mi) wells are connected at the bottom. Water inserted in one well emerges at a temperature of 190°C (375°F) from the other. The plant produces 4 megawatts of electricity. *See also* 1903 ENER.

Σ Mathematics

Ramachandran Balasubramanian, Jean-Marc Deshouillers, and François Dress show that every natural

number is the sum of at most 19 fourth powers, a conjecture first put forth by Edward Waring in 1770. Waring also thought every natural number is the sum of at most nine cubes, which remains unproven. *See also* 1770 MATH.

♥ Medicine & health

A team from MIT led by Robert A. Weinberg announces on October 16 the discovery of a gene that can suppress the cancer retinoblastoma. It is the first gene known to inhibit tumor growth.

Louis Kunkel [b. New York, October 13, 1949] and coworkers discover the gene that is defective in Duchenne muscular dystrophy, a common, fatal form of the disease. *See also* 1983 MED; 1988 MED.

The U.S. Food and Drug Administration in July approves a hepatitis B vaccine made by yeast (Chiron's Recombivax HB), the first vaccine to be approved for humans that is produced by genetic engineering. *See also* 1981 MED.

In Europe the first stent is implanted in a coronary artery. The stent is a coil that is used to keep the artery from narrowing again after angioplasty.

The U.S. Food and Drug Administration approves OKT3, the first monoclonal antibody to be approved for therapeutic use in humans; it aids in organ transplants. *See also* 1975 MED.

Tony Hodges patents a split computer keyboard (the two halves can be adjusted to different angles of attack for each hand) to prevent such repetitive stress injuries as carpal

tunnel syndrome. *See also* 1993 MED.

⌘ Physics

K. Alex Müller [b. Basle, Switzerland, April 20, 1927] and J. Georg Bednorz [b. Neuenkirchen (Germany), May 16, 1950] discover an oxide combination that is superconducting at 30 K (30°C, or 54°F, above absolute zero), the highest known temperature for superconductivity. It is a breakthrough that leads to other materials that are superconducting at much higher temperatures. *See also* 1911 PHY; 1987 PHY.

Steven Chu [b. St. Louis, Missouri, February 28, 1948], John Bjorkholm, Alex Cable, and Arthur Ashkin trap individual atoms using the radiation pressure of a laser, creating optical tweezers. Particles are kept in place because they move toward a region of maximum laser intensity. *See also* 1997 PHY.

Gerd Binning and Heinrich Rohrer of IBM win a Nobel Prize in physics for their 1981 invention of the scanning tunneling microscope (STM), a device used to image surfaces closely, even in terms of individual molecules or atoms. *See also* 1981 TOOL.

✈ Transportation

The space shuttle *Columbia* begins a mission on January 12. The crew includes Charles Bolden, Jr., Robert Cenker, Franklin Chang-Diaz, Robert Gibson, Steven Hawley, George Nelson, and Bill Nelson, the first U.S. congressman in space.

The last mission of the U.S. *Challenger* begins and ends after 73 seconds on January

28. Seals called O-rings in the solid-fuel boosters wear through, causing the entire fuel supply to explode. The blast kills elementary school teacher Christa McAuliffe and astronauts Ronald McNair, Ellison Onizuka, Judith Resnik, Francis Scobee, Michael Smith, and Gregory Jarvis. *See also* 1985 TRAN.

The Soviet space station *Mir* (Peace), a more modern version of the *Salyut* 7, is launched without a crew by the Soviet Union (Russia) on February 20. Vladimir Solovyev and Leonid Kizim are launched on the *Soyuz T 15* mission on May 5. They become the first cosmonauts to board the *Mir* space station. *Mir* becomes the first space station to remain in regular use with human crews aboard for any length of time. *See also* 1987 TRAN.

A bicycle designed by Gardner Martin and powered by Fred Markham sets on May 11 the human-powered land speed record of 105.37 km (65.48 mi) per hour.

The European A320 Airbus is the first commercial aircraft to use a "fly-by-wire" system. As part of the electronic control system (which replaces hydraulic controls), a computer makes some of the decisions for the pilot.

Richard G. (Dick) Rutan [b. Loma Linda, California, July 1, 1938] and Jeana Yeager [b. Fort Worth, Texas, May 18, 1952] pilot the lightweight airplane *Voyager*, entirely built of composites and designed by Elbert L. (Burt) Rutan [b. Dinuba, California, June 17, 1943], around the world without refueling in a nine-day trip that starts on December 14. *See also* 1990 TRAN.

High-temperature superconductors

One of the most important breakthroughs in experimental physics was the discovery by the Dutch physicist Heike Kamerlingh Onnes in 1911 that electrical resistance in mercury vanishes when it is cooled to temperatures close to absolute zero, which is 0 K (-273.15°C or -459.7°F). This phenomenon is known as superconductivity. Soon it was found that other metals and alloys also become superconducting at very low temperatures. For example, if one cools a ring of lead below 7.22 K (-265.93°C or -446.67°F) and induces a current in it, this current will keep flowing indefinitely.

It was not until 1957, more than 45 years after the discovery of superconductivity, that a theory explaining the phenomenon was articulated. According to the BCS theory, named after the American physicists John Bardeen, Leon N. Cooper, and J. Robert Schrieffer, the superconducting current is carried by electrons linked together through lattice vibrations (phonons), a combination that does not dissipate energy through electrical resistance.

The temperature at which a metal becomes superconducting is called the critical temperature. The higher the critical temperature of a metal or alloy, the easier the material is to use in technical applications. Superconductors have only found a marginal application in technology, however, because of the need for extreme cold. Metallic superconductors, such as the alloy of niobium and titanium often used in coils for magnets, require liquid helium at 4 K (-269°C or -452°F) for cooling. Liquid helium is expensive and superconductors remain restricted primarily to applications where the high cost of their operation is justified, as in deflection magnets used in very large particle accelerators and in magnets used for nuclear magnetic resonance imaging.

In 1986 two scientists working for IBM in Switzerland, Georg Bednorz and Alex Müller, found that certain ceramic materials that normally are electrical insulators become superconducting at low temperatures. The materials they first experimented with were made from copper oxide, lanthanum, and barium. The greatest surprise of all was the temperature at which these materials became superconducting, 30 K (-243°C or -405°F), which was higher than for any metallic superconductor. The importance of this discovery can be judged by the fact that Bednorz and Müller were awarded the Nobel Prize in physics just a year later.

An impressive series of breakthroughs followed, and for a time the discovery of a new material with a higher critical temperature was announced every few weeks. In February 1987 a team at Houston University created a superconductor with a critical temperature of 93 K (-180°C or -292°F), and in June 1988 scientists at the IBM Almaden Research Center achieved a critical temperature of 127 K (-146°C or -231°F). It looked as if the series of superconducting compounds with increasingly higher critical temperatures would go on indefinitely and that the creation of room-temperature superconductors would become an attainable

dream. So far, however, this has not happened. In 2001 Jun Akimitsu of Aoyama Gakuin University in Tokyo and coworkers discovered that the common, simple compound magnesium diboride is a superconductor at temperatures as high as 39 K (-234°C or -389°F), which is considerably higher than the ordinary BCS superconductors, but not quite as high as the ceramic high-temperature superconductors. So far, the record critical temperature is from mercury-thallium-barium-calcium-copper-oxygen that becomes superconducting at 138 K (-135°C or -211°F).

From a technical point of view, the most striking advantage of ceramic superconductors is that they can operate when cooled by liquid nitrogen. The boiling point of nitrogen is 77 K (-196°C or -321°F). Liquid nitrogen is much cheaper than liquid helium (used to cool ordinary superconductors), and the required cooling machinery is much easier to operate. Shortly after the discovery of the high-temperature superconductors, it seemed possible that ceramic superconductors would soon replace the conventional superconductors cooled with liquid helium. However, a series of difficulties with the ceramic materials have largely delayed applications on a grand scale. During the early 1990s, several successes in the attempts to apply high-temperature superconductors have restored hope that they will play an important role in technology in the near future.

One of the biggest problems with ceramic superconductors is that it is very difficult to shape them into forms that are useful. One way of preparing ceramic superconductors employs the sintering techniques commonly used for manufacture of other ceramic materials. Reagents in powder form are mixed, ground, and baked. A solid-state reaction forms the final compound. This material is very brittle and therefore not very suitable for making wires or coils.

Another way of obtaining superconducting materials is the creation of films. Films are not only more flexible but can be used in electronic circuits. Superconducting films are produced by a technique called physical vapor deposition. In one method the superconducting material is vaporized by a laser beam and is allowed to condense on a surface of a substrate that is placed close to the superconducting material. Such films are more flexible, and scientists create wires and coils from them by bundling strips of film together. Some of these films can carry several ten-thousands of amperes per square centimeter when no magnetic field is present.

The most important and immediate applications of superconducting films are in electronic circuits. One such application is in microwave circuits. Microwave signals flow in a very thin layer on the outer surface of a conductor and therefore are affected considerably by the conductor's resistance.

The Josephson junction is the most likely active electronic device based on superconductors that will find applications in technology. A Josephson junction consists of two superconducting regions that are very close together, separated by an insulating or

nonsuperconducting layer. Because of a quantum-mechanical effect, superconducting charge carriers can pass from one region to the other. Josephson junctions have several interesting properties. One of them is that the junction can occupy two distinct voltage states, and thus can be integrated in flip-flop or switching circuits. Because circuits based on Josephson junctions can operate much faster than those based on semiconductors, scientists expect that they will be used in the future in very fast computers.

Josephson junctions can also sense extremely small electric currents and voltages and are therefore used in SQUIDs (an acronym for Superconducting QUantum Interference Device). SQUIDs have been previously developed with conventional superconductors but now also exist made from high-temperature superconducting materials. A SQUID consists of a tiny ring of superconducting material that incorporates one or two Josephson junctions; it can detect very small magnetic fields, such as those created by the human heart or brain.

Besides electronics, high-temperature superconductors will probably cause a revolution in energy creation and transport, making the high-voltage lines that now disfigure the perimeters of large cities as much a thing of the past as the steam pipes of the industrial cities of a hundred years ago.

The most important application of superconducting wires and coils will be in the transformation and storage of energy. Magnets made with superconducting coils produce much stronger magnetic fields than those currently used in motors and generators; they are used in a number of large particle accelerators. Superconducting coils are used in prototype motors and transformers, allowing their size to be reduced considerably.

Because a current in a superconducting closed loop flows indefinitely, such a loop can be used for energy storage. The stored energy can be used when required by breaking the closed circuit. Plans exist for building huge superconducting coils mounted underground to store thousands of megawatts of energy.

Scientists are also investigating how they can apply an interesting property of superconducting materials, that of being able to remain suspended in a magnetic field, a phenomenon called magnetic levitation. Obvious candidates to make use of magnetic levitation are maglev trains, trains that move suspended above "magnetic rails." Another application under investigation are magnetic bearings in which the rotating parts do not make any mechanical contact with the outer casing of the bearing.

1987

■ Archaeology

In May workers digging an irrigation ditch near Wenatchee, Washington, find six Clovis spear points. Peter Mehringer starts a study of the site, dating it at about 11,500 years old, the first undisturbed Clovis site known. Most anthropologists believe the Clovis people were the first humans in the Americas. *See also* 1978 ARCH.

Harvey Weiss announces the discovery of 1100 Akkadian clay tablets, the largest cache of cuneiform tablets found since 1933. The tablets, dating from about 1740 BCE to 1725 BCE, from northern Mesopotamia at a place called Tell Leilan, had been excavated in September and October 1986.

David Stuart, a student at Princeton University working for William L. Fash, discovers

a new find at Copán, the most worked-over of Mayan cities. Stuart uncovers a cache that includes jade pieces, a flint knife thought to have been used in human sacrifice, and instruments for ritual blood letting. *See also* 1984 ARCH.

A team of scientists coordinated by Farouk el-Baz [b. Zagazig, Egypt, January 1, 1938] drills into a chamber at the base of the Great Pyramid at Giza, Egypt, to assess the air and the condition of a boat believed to be buried in the chamber. The hope for obtaining ancient Egyptian air is not realized but the boat is located. Farouk el-Baz will report in 1988 that the chamber contains hot, humid air that is a danger to the 4600-year-old boat. *See also* 1984 ARCH.

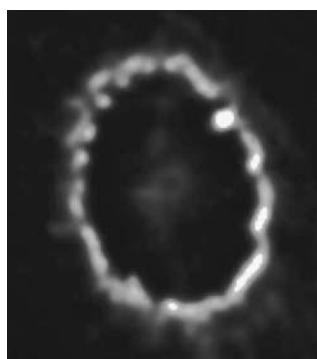
Susan Pevonak, a student volunteer working for Dale Croes at a Coast Indian site near Sekiu, Washington, finds a

microlith attached to a wooden handle. It is the first of the small stone blades, which are known from many sites around the world, ever found attached. It provides insights into how the tools were used. *See also* 15,000 BCE TOOL.

★ Astronomy

Shortly past midnight on February 24 Ian Shelton observes the nearest observable supernova to Earth since 1604 (also photographed by Robert McNaught on February 23, but not noticed until plate is developed). The supernova in the Large Magellanic Cloud (LMC), now known as Supernova 1987A, was formerly the blue giant star Sanduleak 69.202. Ten neutrinos from the explosion are detected by the team of Masatoshi Koshiba [b. Toyohashi, Japan, September 19, 1926] at the Kamiokande neutrino telescope in Japan, and another

eight neutrinos are observed at the IMB neutrino telescope in Ohio on February 23.



RING AROUND WHERE SUPERNOVA 1987A EXPLODED Before the supernova exploded, it released a ring of gas that had already traveled far by the time of the actual explosion. When radiation from the explosion reached the ring, which was approximately 1.3 light-years in diameter, the ring began to glow brightly, although it has gradually faded as radiation from the supernova has diminished.

The supernova becomes as bright as the combined light of all the stars of the LMC. *See also* 2002 PHY.

Benjamin Zuckerman and Eric E. Becklin report that they have found a brown dwarf in orbit around Giclas 29–38, about 50 light-years from Earth. The brown dwarf, a starlike body that is too small to produce full-scale nuclear fusion but too large to be classed as a planet, is manifested as excess infrared radiation. Later studies will suggest that it is a dust cloud. *See also* 1999 AST.

Brent Tully's paper announcing his discovery of the Pisces-Cetus Supercluster Complex, the largest structure discovered thus far in the universe, appears in the *Astrophysical Journal*. *See also* 1953 AST.

C. Roger Lynds and Vahe Petrosian in January locate two enormous arcs of light, each larger than a single galaxy. By November they have established that one of the arcs, in Abell 370, is the image of a far-distant, unseen galaxy that has been distorted by a gravitational lens. It is thought that the other is also the result of a gravitational lens. *See also* 1979 AST.

Jules Halpern discovers a very hot star at the location of an invisible gamma-ray source termed Geminga. *See also* 1973 AST.

Francesco Paresce and Christopher Burrows discover a disk of larger particles around the star Beta Pictoris (at a distance of 53 light-years), which they believe to be a disk of protoplanets, objects that will eventually crash into each other and fuse to form planets. *See also* 1984 AST.

Biology

Jack Strominger, Donald Wiley [b. October 21, 1944, d. Memphis, Tennessee, November 16, 2001], and coworkers determine the three-dimensional structure of the major histocompatibility protein, an essential part of the immune system. Part of the structure appears to be a pocket that holds and binds an antigen. *See also* 1967 MED.

Hans Fricke uses a submersible to observe coelacanths, the famous "living-fossil" fish, in their natural habitat in the deep Indian Ocean. Instead of crawling on the ocean floor as some scientists expected, the fish swim slowly and frequently perform headstands or swim upside down. *See also* 1938 BIO.

Hans Thoenen isolates brain-derived neurotrophic factor (BDF), a growth factor that directs the position and growth of brain cells.

The genomes for a virus that causes dengue fever (type 1) and for the hepatitis A virus are sequenced. *See also* 1985 BIO; 1988 BIO.

For the first time a crime suspect is convicted on the basis of genetic fingerprinting in the United Kingdom. Later in the year, the same technique is used in resolving a rape case in the United States. *See also* 1984 BIO.

The first test of free-living genetically engineered bacteria is conducted when scientists on April 24 spray strawberry fields with bacteria that have had an ice-forming gene deleted. *See also* 1986 BIO.

Chemistry

Charles J. Pedersen and Don-

ald J. Cram of the United States and Jean-Marie Lehn of France win the Nobel Prize in chemistry for their work in making complicated molecules that perform the same functions as natural proteins. *See also* 1960 CHEM; 1967 CHEM.

Communication

Telephones become available on Japanese airliners; calls are relayed by satellite. *See also* 1991 COMM.

Sega Electronics introduces a 3-D video game; images for the left and right eye are displayed in quick alternation (every 1/60 second) on a screen while the viewer looks at the picture with special liquid crystal glasses that pass light in quick alternation. When the left image is displayed on screen, the left lens of the glasses is transparent, and vice versa. The alternation of images is so fast that the eye combines it into a three-dimensional image. *See also* 1972 COMM.

Earth science

James Ryan reports in May that the U.S. National Aeronautics and Space Administration (NASA) has definitely detected the motion of Earth's crustal plates using very-long-baseline interferometry and radio noise from distant quasars, thus confirming plate tectonics. *See also* 1963 EAR.

Wade Miller discovers a fossilized dinosaur egg that contains the oldest known embryo of any kind, probably the embryo of an allosaur from about 150,000,000 years ago. The embryo is detected by X rays of the egg and is less than 2 cm (1 in.) long.

Kevin Aulenback discovers the second known cache of dinosaur eggs that contain fossilized unhatched dinosaurs, probably duck-billed dinosaurs, near Milk River in Alberta, Canada. *See also* 1926 ANTH; 1995 EAR.

Ecology & the environment

The headquarters of the Internationale Nederlanden Group Bank in Amsterdam, the Netherlands, is completed; its ten skylight-topped towers are contoured to maximize natural lighting, produce solar heating, and deflect the wind, making it one of the best-known examples of the "green architecture" movement for commercial buildings. *See also* 1992 ECOL.

Orange Band, the last dusky seaside sparrow, dies in captivity of old age, completing the extinction of the species. Some of the species' genetic heritage has been preserved, however, by a program of crossbreeding the last five dusky seaside males with females of the closely related Scott's seaside sparrow.

The American alligator (*Alligator mississippiensis*) is removed from the U.S. Endangered Species List. Relentless hunting of the species to obtain their hides for leather was the cause of endangerment. A rapid breeder, they quickly recovered while they were protected. *See also* 1985 ECOL; 1994 ECOL.

In an effort to save the California condor (*Gymnogyps californianus*), the last wild bird is captured and brought into a captive breeding program. Beginning in 1992,

young birds will be released in the wild.

■ Electronics

David Miller at Bell Labs invents the Symmetric Self-Electro-optic Effect Device, S-SEED, an electrooptical component that alters its reflectivity to light when irradiated by a laser. The S-SEED will later be used as a component of the first optical computer, built in 1990. *See also* 1990 ELEC.

Computer chips are manufactured with 1 megabit (1000 kilobits or 1,048,576 bits) of computer memory; in February IBM and Nippon Telephone and Telegraph Limited (NTT) of Japan introduce experimental 4 and 16 megabit chips. *See also* 1984 ELEC; 1990 ELEC.

◊ Materials

A Japanese firm, Nippon Zeon, develops a plastic with memory. Upon deformation, it bends and keeps its bent shape at low and modest temperatures. It returns to its initial form when heated to a temperature of 37°C (99°F). *See also* 1962 MATR.

A team led by Paul Ching-Wu Chu [b. Hunan, China, December 2, 1941] becomes the first group to make a material that is superconducting at the temperature of liquid nitrogen, which is 77 K (-196°C , or -321°F). *See also* 1986 PHY; 1988 PHY.

Σ Mathematics

Yasumasa Kanada, David Bailey, Jonathan Borwein, and Peter Borwein calculate π to 134,000,000 decimal places, using a NEC SX-2 supercomputer. *See also* 1995 MATH.

♥ Medicine & health

Luc Montagnier and Robert Gallo agree with each other on sharing credit for discovering HIV, the virus that causes AIDS, publishing their agreement in *Nature*. *See also* 1984 MED.

Kevin P. Campbell and Roberto Coronado announce in December that they have located the protein used to regulate the passage of calcium into and out of muscle cells, the key step in muscle contraction or relaxation. The new protein is named the calcium release channel.

Sir Walter Bodmer [b. Frankfurt am Main, Germany, 1936], Ellen Solomon, H.J.R. Bussey, and Alec Jeffreys announce that they have found a marker for a gene that causes cancer of the colon. *See also* 1978 MED.

A team led by A. Hari Reddi at the National Institutes of Health extracts and identifies bone morphogenetic protein (B.M.P.), a substance predicted first by Marshall Urist in the 1960s. B.M.P encourages new bone to grow and is expected to help cure fractures that otherwise are resistant to healing as well as speeding healing in more ordinary fractures and bone damage caused by surgery.

Experimental vaccination of foxes against rabies begins in Belgium, using baits containing a vaccine created by genetic engineering and dropped from helicopters. The experiment is successful and leads to large-scale vaccination campaigns. *See also* 1885 MED; 1990 MED.

The antidepressant drug fluoxetine, better known by its trade name of Prozac, is

licensed by the U.S. Food and Drug Administration. It works by reducing the uptake of serotonin by brain cells, permitting more to be available at nerve endings — hence it is termed a "serotonin uptake inhibitor." *See also* 1952 MED.

Susumu Tonegawa of the United States wins the Nobel Prize for physiology or medicine for his studies of antibodies and the immune system. *See also* 1976 BIO.

❀ Physics

Michael K. Moe, Alan A. Hahn, and Steve R. Elliot observe the double beta decay of selenium-82, predicted since 1935 but previously unobserved; they also establish that selenium-82 has the longest half-life ever measured: 1.1×10^{20} years.

Dieter Kroekel, Naomi Halas, Giampiero Giuliani, and Daniel Grischkowsky of IBM produce a "dark-pulse" soliton, a standing wave that propagates through an optical fiber without spreading and which consists of a short interruption of a light pulse. *See also* 1980 PHY.

Georg Bednorz of West Germany and K. Alex Müller of Switzerland win the Nobel Prize in physics for their discovery of superconductivity in a material at a higher temperature than previously known. *See also* 1986 PHY.

I Tools

Arthur Rich and James Van House develop the positron microscope. The microscope functions in a similar way as an electron microscope, but uses positrons emitted from a radioactive source. *See also* 1985 TOOL.

The American company 3 D Systems develops a system to produce plastic prototypes of objects designed by CAD (computer-aided design) techniques; they polymerize a liquid plastic into the computer-designed shape with an ultraviolet laser beam steered by a computer. The newly created object can then be lifted out of the liquid plastic. *See also* 1964 COMM; 1991 TOOL.

Cornell University in Ithaca New York opens a new laboratory for the development of tiny, submicroscopic tools. It is called the National Nanofabrication Facility. *See also* 1959 TOOL; 1988 TOOL.

→ Transportation

Two Soviet cosmonauts begin long tours in space on the *Soyuz TM 2* mission. Yuri V. Romanenko returns to Earth from the *Mir* space station after 326 days in space, a new record. Two cosmonauts and Muhammad Faris, the first Syrian in space, begin the eight-day *Soyuz TM 3* mission. The *Soyuz TM 4* mission begins on December 20. Three cosmonauts set a new record of 366 days in space about the *Mir* space station. *See also* 1986 TRAN.

A subway system controlled by computers using fuzzy logic, designed by Serji Yasunobu of Hitachi, starts operation in Sendai, Japan, 320 km (200 mi) north of Tokyo. *See also* 1985 ELEC.

◀ Anthropology

French and Israeli scientists announce that fossils found in a cave in Israel are the 92,000-year-old remains of modern-

type *Homo sapiens*, more than doubling the length of time that modern humans are known to have existed. See also 1868 ANTH.

■ Archaeology

Thomas D. Dillehay and Michael B. Collins report that charcoal dating of artifacts found at Monte Verde in southern Chile indicates that people have been present in the Americas for at least 33,000 years. This date is widely disputed, although later results establish that Monte Verde was occupied very early. See also 1978 ARCH; 1997 ARCH.

Andrea Caradini and coworkers in June discover a wall on the Palatine Hill in Rome that dates from the seventh century BCE, tending to confirm legendary accounts of the foundation of Rome.

German Egyptologist Günter Dreyer excavates at Abydos on the Middle Nile the tomb of Scorpion I, who lived about 3150 BCE. The tomb contains, among other relics, 700 jars that once held about 4550 L (1200 gal) of wine, identified as from Israel or Jordan by analyzing the dregs found in the jars.

★ Astronomy

Results with the underground Kamiokande II detector in a zinc mine in Japan show that it detects solar neutrinos, but that there are fewer than predicted by theory. This result confirms the measurements made by Raymond Davis, Jr. [b. Washington, DC, October 14, 1914] at the Homestake mine neutrino telescope. See also 1965 AST; 1998 AST.

Scientists in an airplane traveling at 12,500 m (41,000 ft)

directly observe the atmosphere of Pluto during its occultation of a star. Previously the atmosphere had been suspected from indirect evidence, but there was considerable controversy over its density. See also 1976 AST.

Simon J. Lilly reports that he has located a fully formed galaxy that is 12,000,000,000 light-years away, and therefore 12,000,000,000 years old, indicating galaxy formation at an early period in the history of the universe.

The large steerable-dish radio telescope at Green Bank, West Virginia, mysteriously collapses on November 15. See also 1962 AST; 2000 AST.

■ Biology

The Human Genome Project is launched in the United States on January 3 with James Watson as its first director. It is a joint program of the National Institutes of Health and the Department of Energy. See also 1984 BIO; 2000 BIO.

Peter Agre [b. 1949], B.M. Denker, B.L. Smith, and F.P. Kuhajada identify a large protein molecule in the outer membranes of kidney cells and red blood cells that appears to control the passage of water into and out of the cells. Later they will confirm this role. See also 2003 BIO.

Manfred J. Lohka and James L. Maller isolate maturation promotion factor (MPF), the substance that initiates meiosis and mitosis in cells. It is a combination of two proteins. See also 1971 BIO.

The DNA sequence is obtained for herpes simplex virus type 1, the cause of cold sores. See also 1987 BIO; 1990 BIO.

■ Chemistry

Chemists estimate that there are 10,000,000 specific chemical compounds that are recorded; each year, 400,000 new compounds are described.

The June 6 issue of *Physical Review Letters* contains the first image of a benzene ring, confirming the ring-structure for aromatics first envisioned by Frederick August Kekulé in 1865. The image has been produced by scientists at IBM's Almaden Research Center in San Jose, California, using the scanning tunneling microscope. See also 1980 COMP.

■ Communication

The first transatlantic optical fiber cable is laid; it can carry 37,800 voice channels. See also 1977 COMM.

Arthur Robinson develops a type of map projection that represents countries near the two poles to their true sizes; this deviates considerably from the traditional Mercator projection. See also 1974 COMM.

The American company Scriptel introduces a method for inputting data into a computer by writing on a screen. See also 1960 COMP.

■ Computers

John L. Gustafson, Gary R. Montry, Robert E. Benner, and coworkers find a way to rewrite problems for computer parallel processing that speeds their solution by a factor of 1000. Previously, an increase in speed by a factor of 100 was thought to be the theoretical limit of this method. See also 1985 COMP.

On November 2 a computer virus developed by Robert T. Morris Jr., a graduate student

at Cornell University is secretly planted in the Internet computer network. It spreads around the world to more than 60,000 computers, tying up thousands of computers for a period of two days. Morris will be eventually expelled from Cornell and fined. See also 1983 COMP.

■ Earth science

The U.S. National Weather Service (NWS) installs the first of 115 Doppler radar systems for weather forecasting. These radars, using the Doppler effect, can measure the speed and direction of wind and storms by measuring small variations in the wavelength of the reflected radar signals. See also 1943 TOOL.

German oceanographer Hartmut Heinrich discovers six separate layers of small stones dropped by icebergs off the coast of France. Soon these same six are found over much of the North Atlantic, and the great waves of icebergs they imply become known as Heinrich events. All such events occurred during the recent Ice Age at intervals of about 10,000 to 50,000 years.

■ Ecology & the environment

James C. Bednarz announces that he has discovered cooperative hunting behavior in family units of Harris's hawks, a hawk species of the New Mexico desert.

In November representatives of 30 nations meet in Geneva, Switzerland, to form the Intergovernmental Panel on Climate Change. Its mission is to consider whether or not the greenhouse effect resulting from human-produced

Communicating with light

Light signals are probably the oldest method for transmitting messages over long distances. Ancient Greeks and Romans used torches for communication between hilltops. Coded messages have long been transmitted from ship to ship with lights.

Alexander Bell was the first to experiment with transmitting speech over light beams. The transmitter of his photophone consisted of a mirror reflecting a light beam. The mirror vibrated when sound waves were directed on it via a horn, causing the intensity of the light beam to vary rapidly. The receiver contained a selenium crystal. Its resistance varied with the fluctuations in intensity in the light beam received from the vibrating mirror. The sound waves were reproduced in an ordinary telephone receiver, which Bell had previously invented.

Lasers can create very short light pulses, much shorter than anything that can be produced with conventional light sources, such as electric lamps. Such short light pulses are suitable for transmitting large quantities of information at high speed. Laser beams have been used in the past for transmitting signals by methods like those used in Bell's photophone, but light traveling through the atmosphere suffers from absorption and dispersion.

Physicists discovered in the 19th century that light can travel through curved glass rods. Light travels through such rods because it bounces off the boundary between the glass and air. At small incident angles, the boundary reflects light just as the flat surface of a pond does, and for the same reason. The index of refraction of air is lower than that of glass, so light striking the boundary is bent.

Glass or quartz rods or silvered tubes are collectively called light guides. In 1880 American engineer William Wheeler proposed piping light into individual rooms in a building using glass rods connected to a central light source. Transmission of telephone signals as modulated light beams through light guides was patented as early as 1934 by Norman French of AT&T. In 1950

Ray D. Kell and George C. Sziklai of RCA proposed transmitting several television channels through light guides.

Proposals to use rods or other light guides failed to result in replacement of the use of electricity through wires. Early light guides were more expensive and less effective than wires.

Instead of a rod, one can use a glass fiber for transmitting light. In a fiber-scope, a large number of parallel fibers carry a complete image: Each fiber transmits the light from one point of the image. A bronchoscope, used in medicine to investigate the trachea, is such a fiber-scope. Besides transmission of the image to the viewer, the fibers also carry the light used for illuminating the field of observation.

In 1966 Charles Kao and George Hockham, two scientists at the Standard Telecommunications Laboratories in England, proposed using optical fibers to replace the traditional cables in telecommunication links. Bell Labs developed an experimental optical-fiber transmission system in 1976 that had the capacity of 45 megabits per second.

The first commercial telephone optical link, 13 km (8 mi) long, was established in Suffolk, England, in 1977 between Martlesham Heath and Ipswich. Since then, telephone companies have increasingly replaced coaxial trunk lines with optical-fiber links. The first transatlantic optical fiber, laid in 1988, can carry 37,800 voice channels simultaneously.

Optical fiber seemed like such a great idea that several companies began to manufacture it in large quantities and telecommunications companies replaced most of their long-distance lines with optical versions. But the need was poorly estimated by the manufacturers. Soon the telecommunications companies had much more capacity than they needed. They had overspent to set up these new networks. The companies that manufactured optical fiber saw sales fall dramatically. The cost related to optical networks and fiber contributed to bankruptcies throughout the telecommunications and glass manufacturing industries around the turn of the 21st century.

changes in atmospheric gases will cause global warming. *See also* 1967 ECOL.

The U.S. Senate ratifies an international treaty, the Montreal Protocol, intended to reduce the use of chlorofluorocarbons, which have been implicated in destroying the protective ozone layer in the atmosphere, making the United States the first nation to ratify the treaty. The treaty will become effective in 1989 after widespread ratification by industrial nations.

British scientists who have been monitoring wave height off of Land's End since 1962 report that the average wave height has increased from 2.3 m (7.4 ft) to 2.7 m (9.0 ft). It is suspected that the change is one consequence of global warming (more frequent and more severe storms).

Italian scientists report that follow-up studies of the people exposed to dioxins in the 1976 industrial accident near Seveso, Italy, show no increase in birth defects. *See also* 1976 ECOL.

Signatories to the 1959 Antarctic Treaty agree on rules for opening the continent to economic exploitation in the form of mining minerals or drilling for oil. All such activities are to be closely monitored to prevent adverse environmental impacts.

Electronics

Motorola launches its 32-bit 88000 series of RISC (reduced instruction set computing) microprocessors; because they handle fewer different instruc-

tions, they can operate much faster than conventional chips, processing as many as 17,000,000 instructions per second. *See also* 1971 ELEC; 1990 ELEC.

Energy

Herman Branover [b. Riga (Latvia), 1931] completes a magnetohydrodynamic generator, Etgar 5, that converts 46 percent of the energy contained in a liquid mixture of lead and bismuth directly into electricity. It is expected that

such generators will eventually have a higher efficiency rate than the classical electric generators. *See also* 1971 ENER.

A vertical-bladed windmill in Hawaii with a single propeller 97.5 m (320 ft) long is installed. It produces 3.2 megawatts of power. *See also* 1941 ENER.

Food & agriculture

Because of concerns about chlorofluorocarbons (CFCs) used in manufacturing foam polystyrene, McDonald's fast-food chain replaces its "clam-shell" foam package for the Big Mac and other sandwiches with a plastic that is not manufactured with CFCs. *See also* 1975 FOOD; 1990 food

Materials

In January scientists from Japan's National Research Institute for Metals develop a new high-temperature superconductor based on bismuth, bringing the number of types of high-temperature superconductors to three. In March scientists at the University of Arkansas discover a fourth type. Based on thallium, the new type quickly sets a high-temperature record for superconductivity of 125 K (-148°F or -234°F). *See also* 1987 MATR; 1989 MATR.

Mathematics

Manfred Padberg [b. Germany, October 10, 1941] and Giovanni Rinaldi solve the traveling salesman problem for 2392 cities, setting a new world's record. *See also* 1973 MATH.

American physicist Stephen Wolfram [b. London, 1959] introduces Mathematica, a software system with graphics ability for use with algebra,

calculus, and other complex mathematical problems.

Medicine & health

William Castelli reports that the Framingham Heart Study has identified enlargement of the left ventricle as a major risk factor for strokes and heart attacks as well as for congestive heart failure. Common causes of an enlarged left ventricle are untreated high blood pressure and overweight.

Graham Colditz and coworkers announce that a study of 120,000 nurses reveals that women who smoke half a pack of cigarettes a day are twice as likely to have strokes as nonsmokers, while women who smoke two packs a day are six times as likely. *See also* 1985 MED; 1993 MED.

Devra Lee Davis and Joel Schwartz report that between 1968 and 1984 the incidence of brain cancer in whites over 75 years old tripled. In the same period, the incidence of cancer of the bone marrow in this group increased by 50 percent. There were no similar increases in younger people.

Louis Kunkel, Eric P. Hoffman, and coworkers announce on May 25 that they have discovered that the protein dystrophin is completely or almost completely absent in cases of Duchenne muscular dystrophy, making it possible for the first time to diagnose the disease accurately in its early stages. *See also* 1986 MED.

Rudolf Jaenisch and coworkers announce on March 10 that they have succeeded in implanting the gene for a hereditary disease of humans in mice. This is believed to

open the way to study such diseases more easily and could lead to improved treatment. *See also* 1986 MED.

Elias James Corey [b. Methuen, Massachusetts, July 12, 1928], Myung-choi Kang, Manoj C. Desai, Arun K. Ghosh, Ioannis N. Houpis, and Wei-guo Su announce the synthesis of ginkgolide B, the chemical thought to be the active ingredient in many herbal remedies based on ginkgo leaves. Ginkgolide B fights asthma and other allergies by suppressing the immune system. *See also* 1990 CHEM.

Harvard Medical School receives a patent, No. 4,736,866, for a mouse genetically engineered to be highly susceptible to cancer. The mouse, the first patented animal in the world (although bacteria had been previously patented), is used in cancer research. It was developed by the American geneticist Philip Leder [b. Washington, DC, November 19, 1934] and Timothy A. Stewart. *See also* 1980 BIO; 1992 MED.

The U.S. Food and Drug Administration approves alpha interferon as a treatment for genital warts. *See also* 1980 BIO.

Drug Delivery Systems develop the electric skin patch. It contains a battery that passes a tiny current through the skin under the patch, reducing its resistance to the absorption of drugs.

RU-486, also called the abortion pill, developed by Etienne-Emile Baulieu, is introduced into general use in France. It induces an abortion up to seven weeks after fertilization by blocking receptors

for the production of the hormone progesterone. *See also* 1956 MED.

Leroy Hood develops a technique similar to PCR (polymerase chain reaction) that uses the enzyme ligase instead of polymerase to reproduce strands of DNA. The ligase chain reaction (LCR) provides an alternative method of gene copying that may be more useful than PCR in many applications. *See also* 1983 BIO.

Disposable contact lenses, which can be worn one to seven days without removal or cleaning, go on sale. *See also* 1965 MED.

Physics

Albert Fert of the University of Paris-Sud and independently Peter Grünberg in Germany discover that the resistance of certain metallic multilayers changes significantly when placed in a magnetic field. This effect is called giant magnetoresistance or GMR. It leads to important improvement in storage and speed of disk drives for computers. *See also* 1993 PHY.

Researchers at AT&T Bell Labs in Murray Hill, New Jersey, report the appearance of magnetic flux lines in ceramic superconducting materials that limit the current density considerably. *See also* 1987 MATR; 1989 PHY.

Leon M. Lederman, Melvin Schwartz, and Jack Steinberger share the Nobel Prize in physics for development of neutrino-beam methods and discovery of the muon neutrino, a neutrino associated with the muon in the same way that the ordinary neutrino is associated with the electron. *See also* 1962 PHY.

I Tools

Paul French and Roy Taylor of Imperial College in London announce a laser that produces X-ray pulses at a wavelength of 248 nanometers and that lasts only 65 femtoseconds, an important step toward the development of useful X-ray lasers. *See also* 1985 TOOL; 1994 TOOL.

Roger Poepel demonstrates the "Meissner Motor," an electric motor based on high-temperature superconductors.

J. Roger Angel in April succeeds in casting a 356-cm (140-in.) diameter telescope mirror by a new method in which the molten glass spins in a rotating mold as it cools; centrifugal forces result in a mirror surface that is already close to the desired paraboloid, requiring much less finishing to obtain a useful reflector. *See also* 1948 TOOL; 1990 TOOL.

Roland Winston [b. Moscow, Soviet Union (Russia), February 12, 1936] supervises a test of a new mirror system that concentrates sunlight to 60,000 times its normal intensity on Earth; it is believed that the system will have applications in the development of new types of lasers and possibly in developing new materials. *See also* 1981 ENER.

Francis C. Moon and Rishi Raj use a high-temperature superconductor to build an almost frictionless high-speed bearing. *See also* 1891 TOOL; 1988 MATR.

Long-Sheng Fan and Yu-Chong Tai at the University of California at Berkeley develop an electric micromotor. The motor is built using etching

technology developed for manufacture of microchips. *See also* 1987 TOOL; 1989 TOOL.

✈ Transportation

Two Soviet cosmonauts and Aleksandr Alexandrov (not the same as the Alexandrov on the *Soyuz TM 3* flight), the first Bulgarian in space, begin the *Soyuz TM 5* mission on June 7. The *Soyuz TM 6* mission begins on August 29, with (Abdul) Ahad (Mohmand), the first Afghan in space, in its crew. On September 6 Ahad and Vladimir Lyakhov are stranded for 24 hours as they attempt to return in *Soyuz TM 5*, but they land safely on September 7. The *Soyuz TM 7* mission begins on November 26 with a three-person crew. The space station *Mir* is temporarily abandoned for the first time when cosmonauts return to Earth.

On September 29 the redesigned U.S. space shuttle *Discovery* begins its first flight since the *Challenger* disaster with a five-person crew: Richard Covey, Frederick Hauck, David Hilmers, John Lounge, and George Nelson. They deploy a satellite. *See also* 1986 TRAN.

On December 2 astronauts Guy Gardner, Robert Gibson, Richard Mullane, Jerry Ross, and William Shepard aboard the space shuttle *Atlantis* begin a four-day "secret" military mission to deploy a radar spy satellite.

In June the European Space Agency launches the first of its third generation of Ariane rockets, the Ariane 4. It is designed to place payloads of up to 4200 kg (9250 lb) into geosynchronous transfer orbit.

The human-powered aircraft *Daedalus 88*, piloted by Kanellos Kanellopoulos, flies from Crete to the shore of Santorini, where it breaks up just offshore in heavy breezes; the flight of 3 hours 54 minutes covers 119 km (74 mi) and sets new distance and time records for human-powered flight. *See also* 1979 TRAN.

1989

★ Astronomy

Duane Muhleman uses the 64-m (210-ft) antenna of the Deep-Space Network at Goldstone to bounce radar signals off Titan, Saturn's largest moon. The returning signals are picked up by the 27 dishes at the Very Large Array in New Mexico and show that part of Titan is covered by a liquid. *See also* 1982 AST; 1990 AST.

On August 25 the U.S. space probe *Voyager 2* makes its closest approach to Neptune, observing great storms on the surface of the planet, discovering six new moons, and clarifying the situation of Neptune's narrow ring system. The rings are very narrow and one has wider clumps in it, so that when seen occulting a star with the clump, the star blinks, but when the star passes in front of a narrower part of the ring, the occultation is not observable from Earth. *See also* 1984 AST.

On October 18 the space probe *Galileo* is launched on a long, looping path toward Jupiter. Along the way it will study Venus, observe Earth from space, and relay pictures and data from asteroids. On reaching Jupiter it will go into



VOYAGER 2 Still the only spacecraft to visit all four of the gas-giant planets, this complex robot captured so many images and relayed back so much data that astronomers continue to learn from the twelve-year planet tour that ended in 1987. Like its twin, *Voyager 1*, this craft continues to travel through space — although *Voyager 1* has gone farther from Earth, because it did not visit the vicinities of Uranus and Neptune as *Voyager 2* did.

orbit about the planet, study the moons, and drop a probe into the atmosphere. *See also* 1991 AST.

✚ Biology

Sidney Altman and Thomas Cech are awarded the Nobel Prize in chemistry for their discovery of the catalytic properties of RNA. *See also* 1984 BIO; 1982 BIO.

↳ Communication

The Japanese Ministry of International Trade and Industry establishes the Laboratory for International Fuzzy Engineering Research. *See also* 1987 TRAN.

On June 3 Japan initiates daily broadcasts of its analog version of high-definition television (HDTV) with a one-hour program featuring the Statue of Liberty and New York Harbor. HDTV pictures are also transmitted between Japan and the United States. *See also* 1991 COMM.

At CERN, Tim Berners-Lee [b. London, June 8, 1955] presents a paper called "Information Management: A Proposal." Although originally intended for use by the physicists at CERN, it becomes the theoretical basis for links used on the Internet and the World Wide Web. *See also* 1990 COMM.

Computers

Computer Deep Thought becomes the first computer to beat a master human chess player when it defeats David

Levy, who had been winning matches against computers since 1968. However, Gary Kasparov defeats Deep Thought in a two-game match on October 22. *See also* 1982 COMP; 1997 COMP.

Seymour Cray founds the Cray Computer Corporation to develop the Cray III supercomputer, which will employ gallium arsenide chips. These are faster than silicon chips but much more expensive. *See also* 1964 COMP; 1991 COMP.

Ecology & the environment

The oil tanker *Exxon Valdez* grounds in Prince William Sound off the coast of southern Alaska, leaking some 35,000 tons of oil into the ocean and having a devastating effect on the fragile ecosystem. The oil spill is thought to kill 350,000 to 390,000 seabirds as well as sea otters and other organisms.

Energy

Scientists at the High Technol-

ogy Center of Boeing develop a stacked photovoltaic cell that converts 37 percent of solar radiation into electricity. The upper cell consists of gallium arsenide and captures the energy of blue light, while the second cell is made of gallium antimonide, converting red light into electricity. In addition, scientists at Scandia National Laboratories develop a single photovoltaic cell containing silicon that converts 20.3 percent of radiation into electricity. *See also* 1954 ENER; 1991 ENER.

Alternative energy sources

Most scientists believe that Earth's atmosphere is warming as a result of the greenhouse effect induced by carbon dioxide from fossil fuel power stations and cars as well as other atmospheric gases. The major alternatives to fossil fuels now in use are waterpower and nuclear power. Waterpower, since the introduction of efficient turbines during the last century, is still the most important energy source that does not use fossil fuels. Although waterpower contributes little to global warming, its main environmental problem has been interference with the natural ecology of rivers (for instance, salmon spawning). Nuclear power, only slightly behind waterpower in terms of total energy production, creates problems with waste disposal and raises the possibility of extensive radioactive contamination if disaster occurs at a plant. Researchers and engineers have been looking at alternative energy sources that do not tax the environment or deplete natural fuel reserves. Between 1986 and 2000 the use of alternative energy sources, such as wind, solar, and renewable biofuels, has increased from 370,000,000,000,000 Btus to 2,990,000,000,000,000 Btus, but it still is not quite 1 percent of all energy.

Wind power, one of the oldest energy sources, has undergone a strong revival since the 1980s. In the Netherlands the sleek rotating blades of modern wind turbines are now as much a mark of the landscape as the traditional windmills. The largest wind turbines can generate more than 2 megawatts of power. More commonly, smaller wind turbines producing about 50 to 100 kilowatts each are grouped in so-called wind farms. Wind supplies a much smaller fraction of electrical energy than nuclear or hydroelectric power. All the wind power generated in 2001

around the world was about the equivalent of ten ordinary nuclear power plants.

Solar energy also supplies a small fraction of the world's total energy demand. There are two main ways to collect solar energy. The most common solar method since the 1970s has been to let the Sun heat water in tubes mounted in special panels on roofs. During the winter water from these solar collectors heats the building and supplies hot water. In some versions, daytime heat is stored in a large insulated tank of water from which it is recovered at night.

The other solar energy method, the use of photovoltaic cells, converts solar energy directly into electricity. During the late 1980s and early 1990s, scientists developed experimental solar cells that convert more than 35 percent of sunlight falling on them into electricity, but practical solar cells available to consumers range from 8 percent to 20 percent efficiency. Solar cells are still too expensive for large solar power stations, but they are now used to supply energy to devices at remote sites. Tax breaks have also made solar cells practical for home use, where the solar cells are on the roof. Home solar systems usually have backup from a conventional power grid and may also sell power to the grid when production of energy exceeds use.

Another alternative source that has increased in usage since the 1970s has been geothermal power, which is already cost effective, although the initial capital investment may be high. Geothermal power taps the interior heat of Earth to produce steam or expand compounds such as ammonia (which does not require as high a temperature as steam does). The expanded gases drive turbines to generate power without pollution. By 2000 geothermal power in the United States was already replacing the energy that would require 60,000,000 barrels of oil to produce.

The Shippingport Atomic Power Station is decommissioned after 32 years of operation. Its radioactive main reactor is taken from Pennsylvania to Hanford Military Reservation in Washington to await approval of a final burial ground. This is the first U.S. nuclear power plant to be dismantled. *See also* 1957 ENER.

❖ Materials

The Martin Marietta Laboratories in Baltimore develop Weldalite 049, an aluminum-lithium alloy that has twice the yield strength (the ability to return to its original shape after being bent) of the leading aluminum-copper alloy used for aerospace. *See also* 1908 MATR.

Σ Mathematics

Gregory and David Chudnovsky calculate the value of π to 1,011,196,691 decimal places. *See also* 1987 MATH; 1999 MATH.

Miklos Laczkovich [b. Budapest, Hungary, February 21, 1948] proves that a circle can be cut into a finite number of pieces and reassembled into a square. This is not the same as "squaring the circle," which merely requires that the square have the same area as the circle.

♥ Medicine & health

On May 10 Thomas H. Shaffer and coworkers show that an oxygen-suffused liquid called a perfluorocarbon can be breathed by a premature infant, reducing the lung damage that such infants often encounter.

J. Michael Bishop and Harold Varmus are awarded the Nobel Prize in physiology or

medicine for their discovery of oncogenes — mutated genes that promote cancerous growth. *See also* 1976 MED.

⌘ Physics

Several groups of researchers discuss the possibility of flux-line pinning to increase the current density of high-temperature superconductors; that is, the immobilization of flux lines in a superconductor by the introduction of impurities or crystal faults. *See also* 1988 PHY; 2002 PHY.

Norman F. Ramsey [b. Washington, DC, August 27, 1915], Hans Dehmelt, and Wolfgang Paul are awarded the Nobel Prize in physics — Ramsey for development of the separated oscillatory field method and its use in atomic clocks and Dehmelt and Paul for the ion trap technique for observing subatomic particles. *See also* 1973 PHY; 1978 PHY.

I Tools

At the end of October the first-ever conference on nanotechnology — manufacture of devices on a nanometer (one-billionth of a meter) scale — takes place in Palo Alto, California, led by K. Eric Drexler of the Foresight Institute. *See also* 1988 TOOL.

↗ Transportation

On March 13 U.S. astronauts James Bagian, John Blaha, James Buchli, Michael Coats, and Robert Springer begin a mission of the space shuttle *Discovery*. NASA's third relay satellite is deployed and the thermal control system is tested for a proposed U.S. space station. On November 22 *Discovery* is launched on a "secret" military mission with a five-person crew: John

Blaha, Manley Carter, Frederick Gregory, Story Musgrave, and Kathryn Thornton.

On May 4 the space shuttle *Atlantis*, crewed by Mary Cleave, Ronald Grabe, Mark Lee, Norman Thagard, and David Walker, begins a mission. It launches the space probe *Magellan*, which will map Venus with radar. On October 18 *Atlantis* begins a five-day mission with Ellen Baker, Franklin Chang-Diaz, Shannon Lucid, Michael McCulley, and Donald Williams. They launch the *Galileo* space probe. *See also* 1989 AST; 1993 AST.

James Adamson, Mark Brown, David Leestma, Richard Richards, and Brewster Shaw, aboard the space shuttle *Columbia*, begin a "secret" military mission on August 9 to launch a spy satellite.

On September 5 the *Soyuz TM* 8, crewed by Alexander Serebrov and Alexander Vikorenko, begins a mission to *Mir* for an extended stay by the cosmonauts, who will remain in space until February 19, 1990.

The *Train à grande vitesse* (TGV), the high-speed train, in France, reaches a record speed of 482 km/h (300 mi/h). *See also* 1981 TRAN; 1990 TRAN.

The U.S. air force introduces the Stealth Bomber (B-2), which, because of its shape and the materials used, is expected to be invisible to radar. In 1991, however, the bomber will be spotted by British radar during the Persian Gulf War.

1990

▲ Archaeology

Cecil Hodder, who in 1989

began using a metal detector in the 40-acre field where the Snettisham torc, a braided gold neck ring, had been found in 1950, discovers on August 25 a bronze vessel containing fragments of about 50 torcs, 70 rings or bracelets, coins, and other bits of metal. Further investigation of the field by the British Museum uncovers another five hoards, including 19 well-preserved gold or silver torcs. *See also* 1950 ARCH; 1992 ARCH.

★ Astronomy

The *Cosmic Background Explorer* (COBE), launched by NASA on November 18, 1989, precisely measures the cosmic background radiation, confirming that it perfectly matches a black-body radiation spectrum of a body at a temperature of 2,735 K (-270.415°C or -454.747°F), and that it has the same intensity in all directions, thus supporting the big bang theory of the evolution of the universe. *See also* 1964 AST.

Mark Showalter discovers by searching 30,000 *Voyager* images a tiny moon, 19 km (12 mi) across, circling Saturn that is responsible for creating the Encke Gap in Saturn's ring system. The moon is later named Pan. *See also* 1989 AST.

The space probe *Magellan*, launched on May 4, 1989, reaches Venus and begins to produce a detailed map of its surface using radar and a 3.66-m (12-ft) diameter antenna. *See also* 1962 AST.

In February, following a suggestion from astronomer Carl Sagan, the *Voyager 1* space probe, near the edge of the solar system, takes a portrait of the system and transmits it back to Earth, the first actual

image of the whole solar system from space. *See also* 1977 AST.

On April 24 the U.S. space shuttle *Discovery* is launched on a five-day mission, during which the *Hubble Space Telescope* is launched. The crew consists of Charles Bolden, Steven Hawley, Bruce McCandless, Loren Shriver, and Kathryn Sullivan. *See also* 1993 AST.

On June 1 *ROSAT*, the *ROentgen SATellite*, is launched. It is a German-British-American satellite that, after surveying the entire sky at X-ray wavelengths, will focus on the 1000 most interesting targets. It will operate until February 12, 1999. *See also* 1996 AST.

On October 6 the space shuttle *Discovery* with astronauts Thomas Akers, Robert Cabana, Bruce Melnick, Richard Richards, and William Shepherd aboard travels into space to launch the European Space Agency spacecraft *Ulysses*, intended to study the Sun from a solar polar orbit (an orbit that passes nearly over the poles of the Sun).

SAGE, the Soviet-American Gallium Experiment, is conducted at the Baksun Neutrino Observatory in Prielbrusye, Russia, in the Caucasus Mountains. SAGE uses 55 metric tons (60 short tons) of liquid gallium metal to observe neutrinos via transmutation of gallium to germanium caused by neutrino impacts. The experiment uses neutrino counts to study the Sun's internal structure and evolution and the center of the Milky Way while looking for neutrinos from the gravitational collapse of stars. *See also* 1991 AST.

Biology

Three laboratories independently discover the first known intein. This is a stretch of DNA mixed into a gene in yeast that is much larger than the protein it encodes but that does not seem to include an intron. The intein produces a large protein that almost immediately vanishes, leaving the smaller protein behind. Scientists soon find dozens of similar inteins. Inteins are flanked by DNA stretches called exteins, and the combination of two exteins and an intein is needed to produce the protein. *See also* 1977 BIO.

The hepatitis C genome is sequenced. *See also* 1988 BIO; 1991 BIO.

The U.S. Congress approves funding of a 15-year project of mapping the human genome. *See also* 1984 BIO; 1999 BIO.

Chemistry

Julius Rebek, Jr. [b. Beregszasz, Hungary, April 11, 1944] of Massachusetts Institute of Technology and coworkers announce the creation of a self-replicating molecule, amino adenosine triad ester (AATE). Placed in a solution of suitable molecular parts, AATE creates copies of itself.

Felipe Gaitan of the University of Mississippi and Lawrence Crum discover that single bubbles formed in the presence of a strong standing sound wave collapse, emitting light. The phenomenon, termed sonoluminescence, is at first thought to be caused by nuclear fusion, but a dozen years of research eventually reveal that high-temperature chemical reactions of the gases inside the bubble cause the phenomenon.

Elias Corey is awarded the Nobel Prize in chemistry for his creation of new ways to synthesize organic molecules. *See also* 1988 MED.

Communication

In December Tim Berners-Lee writes the program that creates the World Wide Web, originally intended as a way of easing communications over the Internet for physicists at CERN. *See also* 1989 COMM; 1991 COMM.

Facsimile transmission machines (faxes) that can transmit color become commercially available. *See also* 1980 COMM.

Computers

Hewlett-Packard announces a computer with a RISC (reduced instruction set computing) processor. The RISC processor allows an increase of processing speed since it does not require those parts of the normal instruction set that are seldom used. Later in the year IBM introduces the RS/6000 family of RISC workstations that, for many applications, are as fast as then current supercomputers. *See also* 1988 COMP.

Construction

On September 29, after exactly 83 years of construction, the Washington National Cathedral (officially the Cathedral Church of St. Peter and St. Paul) is completed in Washington, DC. The Gothic edifice had been used in an incomplete form since 1912.

The Basilica of Our Lady of Peace in Yamoussoukro, Ivory Coast, is completed. It replaces St. Peter's in Rome as the world's largest church. *See also* 1626 CONS.

Earth science

Kathleen Crane and a Russian-American team discover hot vents in the floor of Lake Baikal (Russia), suggesting that the lake may be a "spreading center," a crack slowly opening in the Asian landmass. *See also* 1986 EAR.

In December David Elliot, Richard Hanson, and William Hammer discover dinosaur fossils from 200,000,000 years BP at Mount Kilpatrick on the continent of Antarctica, the first such find on the continent and the second dinosaur fossils discovered in the south polar regions.

In South Dakota, Sue Hendrickson [b. December 2, 1949] uncovers the largest, most complete fossil of *Tyrannosaurus rex* yet found. The fossil is named Sue, after its discoverer. *See also* 2000 EAR.

Ecology & the environment

In June the Montreal Protocol Amendments, calling for a worldwide phase-out of the use and manufacture of chlorofluorocarbons and other ozone-depleting gases, is passed in London. *See also* 1978 ECOL; 1991 ECOL.

Electronics

In January Intel introduces the 486 microprocessor chip, which can operate at a rate of 33 megahertz. The first computer equipped with the new chip is the PowerCache 33/4 built by Advanced Logic Research. *See also* 1985 ELEC; 1993 ELEC.

IBM develops a transistor that can operate at 75 megahertz. *See also* 1988 ELEC; 1992 ELEC.

In June Hitachi announces a

working prototype of a 64-megabit memory chip. *See also* 1987 ELEC; 1991 ELEC.

On January 29 a team of scientists at Bell Laboratories led by Alan Huang demonstrates the first all-optical processor. The assembly of lasers, lenses, and fast light switches has the same capacity as the kind of electronic chip used to control a dishwasher. Although the processor can perform calculations optically, it is programmed by a separate electronic computer of the ordinary, nonoptical variety. *See also* 1987 ELEC; 1993 ELEC.

Richard Friend and coworkers at the University of Cambridge's Cavendish Laboratory make a light-emitting diode (LED) by sandwiching semiconducting films of the plastic PPV between two metallic electrodes, a simple, but unexpected way to produce light. The discovery is made because they are performing an unrelated measurement in a very dark room, so the dim light produced becomes apparent. *See also* 1970 ELEC; 1993 ELEC.

II Food & agriculture

The Dutch government approves a plan to repurchase lowland regions reclaimed from the sea and return them to a more natural state of marshland or periodically flooded forest. When complete, the plan will affect a tenth of all farmland in the Netherlands, restoring 250,000 h (600,000 a) to an approximation of its original state. This reverses a trend that began in Holland about 500 CE. *See also* 1653 FOOD.

Because of concern over plastic's lack of biodegradability in landfills or when otherwise

discarded, the fast-food chain McDonald's replaces its plastic sandwich packaging with paper. *See also* 1988 FOOD.

◊ Materials

Researchers at Lawrence Livermore National Laboratory develop a silicon dioxide aerogel that weighs only 0.005 g per cm³ (5 oz per cu ft).

Fumihiro Wakai and coworkers at Japan's Government Industrial Research Institute in Nagoya develop a stretchable ceramic made from a mixture of silicon nitride, silicon carbide, and other compounds. Potential uses of this ceramic material are engine parts that can withstand heat and that can be manufactured into different shapes of high precision. *See also* 1985 MATR.

In July workers in the United States report that they can grow pure carbon-12 diamond films that conduct heat 50 percent better than natural diamond, which contains 1 percent of the isotope carbon-13. Pure carbon-12 diamond also can withstand laser radiation better than natural diamond. *See also* 1981 MATR; 1991 MATR.

Leigh T. Canham discovers a method for producing light by etching silicon with a strong acid; this produces a porous substance similar to a sponge. When electricity is passed through the porous silicon, it glows. *See also* 2002 MATR.

Σ Mathematics

Henryk Wozniakowski [b. Lublin, Poland, August 31, 1946] develops the "silver dagger" algorithm, a much faster way to perform complex calculations needed in parts of the integral calculus.

♥ Medicine & health

The U.S. National Institutes of Health treat a four-year-old girl with ADA deficiency (lack of an immune response caused by a defect in the gene for adenosine deaminase) by administering to her billions of cells with a gene she lacks. It is the first sanctioned attempt at human gene therapy and only partly successful. *See also* 2000 MED.

On June 7 a genetically engineered live virus is deliberately introduced into the U.S. environment for the first time; the virus is a vaccine against rabies mixed with raccoon bait. It is tested for safety by release in a northeastern Pennsylvania wilderness region where it is expected to immunize raccoons, indirectly preventing humans from acquiring the disease. *See also* 1987 MED.

The Jarvik 7 artificial heart is abandoned because of the substandard life quality it imposes on its recipients, who must be attached by a tube to machinery at all times. *See also* 1982 MED; 2001 MED.

Joseph E. Murray [b. Milford, Massachusetts, April 1, 1919] and E. Donnall Thomas are awarded the Nobel Prize in physiology or medicine for their discoveries concerning organ and cell transplantation in the treatment of human disease. Murray performed the first kidney transplant; Thomas performed the first successful bone-marrow transplant. *See also* 1956 MED.

⊗ Physics

On January 1 the volt (measuring electrical potential) and the ohm (measuring electrical resistance) are defined

in atomic terms, replacing the specified 19th-century meters and equipment used in the previous definition. Because the volt and ohm are tied to the ampere, which was not redefined, the new definitions — unlike those for the second and meter — will have little application unless they are later adopted as fundamental units. *See also* 1967 COMM.

Richard E. Taylor [b. Medicine Hat, Alberta, Canada, November 2, 1929], Jerome I. Friedman [b. Chicago, Illinois, March 28, 1930], and Henry Way Kendall [b. Boston, Massachusetts, December 9, 1926, d. Wakulla Springs, Florida, February 15, 1999] are awarded the Nobel Prize in physics for experiments between 1967 and 1973 that confirmed the existence of quarks.

I Tools

Donald M. Eigler and coworkers show that they can move a single xenon atom back and forth between a surface and the tip of a scanning tunneling microscope, considered a step toward developing a switch based on moving a single atom. This could be used to produce very small transistors. *See also* 1991 TOOL.

↗ Transportation

On January 9 the U.S. space shuttle *Columbia* begins a ten-day, 21-hour mission (the longest shuttle flight to date). The crew is Daniel Brandenstein, Bonnie Dunbar, Marsha Ivins, David Low, and James Wetherbee. They launch the communications satellite *Symcom IV* and retrieve the *Long Duration Exposure Facility*, which has been in orbit since April 7, 1984. After return, problems are found with

fibers in working parts of the shuttle. *Columbia* begins a nine-day mission with a seven-person crew on December 2 after long delays caused by leaking hydrogen. The shuttle carries a set of three ultraviolet telescopes and one X-ray telescope, as well as an instrument called ASTRO-1, into space.

On February 28 the space shuttle *Atlantis* begins a "secret" military mission with a five-person crew: John Casper, John Creighton, David Hilmers, Richard Mullane, and Pierre Thuot. It launches a spy satellite that fails and burns in the atmosphere. On November 15 *Atlantis* begins a six-day "secret" military mission, proclaimed as the last military mission that will be intended to be kept from the public. This crew is Richard Coverly, Frank Culbertson, Charles Gamar, Carl Mead, and Robert Springer.

On February 11 Russian cosmonauts Anatoly Solov'yev and Aleksander Balandin begin the *Soyuz TM 9* mission to relieve Alexander S. Vitorenko and Alexander A. Serebrov. On July 18 Solov'yev and Balandin are briefly trapped outside *Mir* by a faulty hatch. Gennadi Manakov and Gennadi Strekalov begin the *Soyuz TM 10* mission on August 4. Viktor Afan'ev and Musa Manarov and Japanese journalist Toyohiro Akiyama (sponsored by Japanese corporations) begin the *Soyuz TM 11* mission to *Mir* on December 2. Afan'ev and Manarov replace Manakov and Strekalov, who return with Akiyama in *Mir*.

Pegasus, a new space booster, is used for the first time to place a payload into Earth

orbit. *Pegasus* is a 15-m (49-ft) rocket attached to a wing of a NASA B-52 airplane; it is released from the plane at an altitude of 13,000 m (43,000 ft). It can launch small payloads into orbit for a cost much less than a rocket leaving the surface of Earth.

On December 1 at 11:21 a.m. local time Robert Graham Fagg and Philippe Cozette meet and shake hands under the English Channel, signaling the meeting of the two parts of the tunnel under the channel, or Chunnel, as it is sometimes known. The breakthrough occurs 22.2 km (13.9 mi) from England and 14.5 km (9.7 mi) from France. See also 1994 TRAN.

Sweden introduces a new computerized railroad car, the X-2000, on the line between Stockholm and Goteborg, cutting 10 percent of the time possible with even the highest-speed trains previously available. The secret of the X-2000 is that special computerized steering and suspension allow it to take curves 30 to 40 percent faster than ordinary railroad cars can do. See also 1989 TRAN.

On March 6 Ed Yeilding and Joseph T. Vida set a speed record for a flight from California to Maryland of 1 hour 8 minutes 17 seconds. They pilot an SR-71 Blackbird spy plane on its way from its California base, where its use is being discontinued, to the Washington, DC, area so that the plane can be displayed at the Smithsonian.

A head-on crash in Culpepper, Virginia, on March 12 is the first actual test of driver's side air bags in the field. Both drivers have air bags, which

both deploy, and both drivers walk away. See also 1953 TRAN.

1991

► Anthropology

French paleontologist Martin Pickford, working in Namibia with a French-American team, discovers part of a jaw of an early ape, later named *Otavipithecus namibiensis*, that may have lived 12,000,000 to 15,000,000 years ago. The jawbone is the first known hominoid fossil from southwestern Africa. See also 2002 ANTH.

French diver Henri Cosquer discovers near Marseilles a submerged cave, now called Cosquer Cave, with wall paintings dating from 19,000 BCE.

► Archaeology

A Copper Age man, called Ötzi by scientists, is discovered in the Italian Alps near Bolzano. Killed by an arrow, this is the best preserved body, clothing, and tools from early Europe. See also 3300 BCE ARCH.

★ Astronomy

American Alexander Wolszczan [b. Poland, 1946] becomes the first to detect an extrasolar planet, which he locates in orbit about a pulsar. He recognizes that a planet is present by observing variations in the pulsar's radio waves caused as the planet's gravity tugs the pulsar back and forth as it orbits. See also 1995 AST.

On April 10 Joss Bland-Hawthorn, Andrew Wilson, and Brent Tully announce their discovery of an object with mass several billion times that of the Sun, possibly the

largest black hole known. It is detected by observing the gravitational attraction on a large rotating disk of gas in the galaxy NGC 6240. Also, Stuart Shapiro and Saul Teukolsky show that it is theoretically possible to receive information from a black hole, so that black holes are not really hidden from view as predicted by relativity theory. See also 1996 AST.

In February Belgian astronomers Olivier Hainaut and Alain Smette discover that Comet Halley, now moving away from the Sun, is 300 times brighter than usual when at this distance from the Sun. The cause appears to be a giant outburst from the comet that brightens the coma (gas and dust cloud around the comet). See also 1985 AST.

The *Galileo* space probe provides the first close-up images of an asteroid, 951 Gaspra, as it flies by on its way to Jupiter. Gaspra is revealed to be an elongated potato-shaped object 19 km (12 mi) long and about 12 km (7 mi) in diameter. See also 1989 AST; 1993 AST.

On April 5 the *Gamma Ray Observatory* (later renamed the *Compton Gamma Ray Observatory*), a 15.5-metric-ton (17-ton) telescope for observing the universe at very short wavelengths, is launched from the space shuttle *Atlantis*. See also 1997 AST.

The New Technology Telescope, built by the European Southern Observatory at La Silla, Chile, which contains a 3.38-m (141-in.) mirror, the shape of which is continuously corrected by 75 computer-controlled actuators, sees first light.



ASTEROID 951 GASGRA This 10-trillion ton rock hurtles in its orbit about the Sun at about twice the distance of Earth from the Sun and with a period of 3.29 years. One of several hundred thousand known asteroids, Gaspra was in the right place at the right time to become the first asteroid to be imaged by a nearby space probe. (The "951" in its designation indicates that it was 951st asteroid to be discovered that has had its orbit determined.)

In the Gran Sasso Tunnel, Italy, astronomers begin conducting the GALLEX experiment, using 30 tons of gallium chloride dissolved in 101 tons of water. The purpose is to study solar neutrinos observed when they strike gallium atoms and transmute them to germanium. The experiment runs through 1997. *See also* 1990 AST; 1998 AST.

In the Mediterranean Sea off the coast of Greece near Pylos, Greek and Russian scientists start a neutrino telescope called NESTOR (Neutrinos from Supernovae and TeV Sources Ocean Range). Twelve photomultipliers are in a titanium structure with six 16-m (52-ft) arms deployed around a central ball and suspended below 3800 m (12,500 ft) of water. The photomultipliers are used to observe Cerenkov radiation produced when high-energy muon neutrinos from galactic and extra-galactic sources pass through the water faster than the speed of light in water. *See also* 1934 PHY.

生物学

The genome of the cytomegalovirus is sequenced. Although this virus causes little damage to healthy people, it can produce serious retinal damage in those with compromised immune systems. *See also* 1990 BIO; 1992 BIO.

Erwin Neher and Bert Sakmann are awarded the Nobel Prize in physiology or medicine for developing the patch-clamp technique, which enabled them to detect and analyze how cells take in and release ions through the cell membrane. *See also* 1976 BIO.

化学

Richard Ernst is awarded the Nobel Prize in chemistry for his development of improvements in nuclear magnetic resonance techniques. *See also* 1966 PHY.

通信

Tim Berners-Lee in the summer of this year begins to install the World Wide Web

on the Internet. *See also* 1990 COMM; 1994 COMM.

After six years of testing, the *New York Times* begins to use an ink developed by the Sun Chemical Company that does not rub off on readers' hands.

The limited broadcasting of analog high-definition television (HDTV) begins in Japan.

Woo Paik and coworkers at the General Instrument Corporation's Videocipher division in San Diego, California, produce the first working prototype of digital high-definition television (HDTV). *See also* 1989 COMM.

Skyphone starts equipping airliners with telephones that remain operational anywhere on Earth. Only outgoing calls are possible, with signals relayed by existing telecommunications satellites. *See also* 1987 COMM.

计算机

Linus Torvalds [b. Helsinki, Finland, December 28, 1969] develops his first version of the operating system Linux. Based on UNIX, it is a direct competitor to Microsoft's Windows. *See also* 1975 COMP.

The Japanese Institute for New Generation Computer Technology develops the Parallel Inference Machine (PIM), a fifth-generation computer that can handle words and images by logical inference, without the requirement that they be represented by numbers. *See also* 1982 COMP.

Cray Research introduces the Cray Y-MP C90 supercomputer. It is equipped with 16 processing chips, and its speed reaches 16 gigaflops (16,000,000,000 calculations per second). *See also* 1989 COMP.

建筑

A new record for the length of a cable-stayed main span for a bridge is set at 527 m (1729 ft) by the Skarnsundet Bridge in Norway. *See also* 1986 CONS.

地球科学

Debris of an asteroid is found in Puerto Chicxulub, Mexico. Evidence suggests that the asteroid must have been 10 to 15 km (6 to 9 mi) in diameter and must have hit Earth with a speed of 150,000 km/h (93,000 mi/h), exploding at sea. Dust, water vapor, and possibly chemicals released by the explosion are thought to have caused a worldwide effect similar to a nuclear winter, with the consequent extinction of the dinosaurs and other species. *See also* 1980 EAR; 2002 EAR.

William M. Gray of Colorado State University finds a strong correlation between the level of rain falling during the summer in the West Sahel region in Africa and the number and strength of hurricanes that reach the United States.

On June 12 the volcano Pinatubo on Luzon Island in the Philippines erupts, putting so much sulfur dioxide into the upper atmosphere that it will cause a cooler climate worldwide for several years. Volcanologists, however, successfully predict the eruption of Pinatubo (and also the eruption of Unzen in Japan), saving thousands of lives.

生态与环境

Iraq dumps more than 1,000,000 tons of oil from Kuwait, which it has invaded and occupied, into the Persian Gulf in response to efforts to

drive the Iraqi army out of Kuwait.

Eight people are sealed inside Biosphere II, a 1.2-h (3-a) glass enclosure containing nearly 4000 plants and animals in a variety of ecosystems, beginning a two-year effort to study the ecology of a closed system. However, many problems occur, requiring oxygen to be pumped in and carbon dioxide removed. Eventually, the enclosure and equipment will be turned over to Columbia University for use in various environmental studies.

The U.S. government mandates on May 7 tests for lead in tap water; it will take about 20 years for tests to be completed and for any problems found to be corrected. On October 7 the United States lowers permissible levels of lead in the blood of children; in November the United States lowers levels of lead that will be allowed to leach from dishes and glassware. *See also* 1979 MED; 1994 MED.

On September 12 the Upper Atmosphere Research Satellite is launched. It is a 6.6-metric-ton (7.25-ton) satellite designed to observe ozone, greenhouse gases, and winds in the upper atmosphere. *See also* 1990 ECOL.

ERS-1, the largest European satellite for environmental research, is launched in French Guyana.

■ Electronics

In August Donald Eigler, Christopher P. Lutz, and William E. Rudge at IBM's Almaden Research Center in San Jose, California, announce that they have developed a tunneling device that acts as a

switch based on the location of a single atom of xenon. Calvin Quate of Stanford University claims that in theory such switches could be used to put the entire collection of the U.S. Library of Congress onto a single disk with a 30-cm (12-in.) diameter. *See also* 1990 TOOL; 1998 ELEC.

In February four Japanese companies — Fujitsu, Matsushita, Mitsubishi, and Toshiba — announce that they have developed an experimental 64-megabyte dynamic random access memory (DRAM) chip. On December 18 IBM and Siemens A.G. of Germany announce that they too have developed jointly a prototype of such a chip. *See also* 1990 COMP.

Information Storage Devices develops a practical analog chip that can store sound without the requirement that the sound be converted into digital form. The sound is sampled and stored as charges in the chip, which can distinguish 230 levels.

Misha Mahowald [b. Minneapolis, Minnesota, 1963] and Rodney Douglas build a chip that simulates neurons; their first chip represents five neurons. *See also* 1986 COMM.

➤ Energy

Philips in the Netherlands develops a light bulb that uses electromagnetic induction to excite a gas to emit light. The bulb has no parts that wear out and can last for 60,000 hours. *See also* 1960 ENER.

The Taliq Corporation of Sunnyside, California, begins marketing windows based on liquid crystals that are transparent in the presence of an electric current but opaque

when the switch is turned off. At a cost of 20 to 30 percent more than plate glass, such window panels are used primarily as dividers and in a few office buildings.

Michael Gratzel and coworkers at the Swiss Federal Institute of Technology in Lausanne patent a type of transparent solar panel that supplies electricity and can be fitted on buildings as ordinary windows. *See also* 1989 ENER; 2003 ENER.

A laboratory in France develops paper-thin electrical batteries that would be suitable for a wide range of applications, including powering cars.

❖ Materials

Sumio Iijima [b. 1939] discovers nanotubes, carbon atoms arranged in tubular structures. Carbon nanotubes are the largest molecules known: Carbon atoms are arranged in hexagonal patterns resembling rolled-up chicken wire. They are about one nanometer thick and up to one millimeter long and can contain millions of atoms. *See also* 1985 MATR; 1999 MATR.

Eli Yablonovich produces "photonic crystals" by drilling holes in a crystalline material so that light of a certain wavelength cannot propagate in the material. Such materials are believed to form a basis for the development of "photonic transistors." *See also* 1987 ELEC.

On April 19 Jagdish Narayan and Vijay Godbole of North Carolina State University and Carl White of the U.S. Oak Ridge National Laboratory announce that they have grown thin single-crystal dia-

mond films on metal surfaces. First efforts result in films only 100 square microns in area. Also, Manuel Nunez-Regueiro produces diamond by compressing C₆₀ (buckminsterfullerene) molecules at room temperature, the first production of artificial diamonds without using very high temperatures. A high pressure of 150 kilobars, or about 150,000 atmospheres, is still required. *See also* 1990 MATR; 1992 MATR.

Scientists in Japan develop a p-n junction diode (transistor) based on diamond. It resists both ionizing radiation and high temperatures better than conventional diodes made from silicon or germanium. *See also* 1990 MATR.

♥ Medicine & health

Eckard Wimmer [b. Berlin, May 22 1936], Akhteruzzaman Molla, and Aniko V. Paul of the State University of New York at Stony Brook announce that they have created complete polio viruses from viral RNA and a cell-free mixture extracted from human cells, the result of a series of attempts that began in 1983.

Kenneth Matsumura at Berkeley develops a tiny electrocardiograph, worn like a wristwatch. By continuously monitoring electric signals from the heart, it can give an early warning of a heart attack. *See also* 1959 MED.

The American physicist William Bennett and his daughter Jean develop the Dynamic Spectral Phonocardiograph (DSP). It contains a sensitive microphone that picks up the sounds of the heartbeat; the intensity of the sound is displayed for differ-



BIOSPHERE II Biosphere II (Earth is counted as Biosphere I) was intended to provide a closed ecosystem where humans could live for as long as two years, and in its initial experiment that nearly took place — one of eight volunteers was removed briefly for surgery on a bad cut and, despite the glass walls and concrete foundation, the ecosystem was not completely closed. After the initial experiment, other ecological experiments have been conducted in the giant greenhouse, focusing for example on the effect of excess carbon dioxide on forest, plain, desert, and reef environments.

ent frequencies on a monitor.
See also 1990 MED.

Steve Barnard and David Walt develop a chemical fiber-optic sensor for analyzing the chemical composition of blood. It consists of a multi-stranded optical fiber with several dye probes at their ends. When illuminated with ultraviolet light, specific dye

probes glow in the presence of various compounds in the blood sample.

A U.S. National Institutes of Mental Health study reports a significant overlap of mental illness with drug or alcohol abuse: Some 30 percent of U.S. adults with mental disorders also have alcohol or drug abuse disorders.

⌘ Physics

Pierre-Gilles de Gennes [b. Paris, October 24, 1932] is awarded the Nobel Prize in physics for his studies of the ordering of molecules, especially in liquid crystals.

I Tools

Stewart Dickson invents a method for producing com-

plex plastic objects by irradiating a liquid polymer with an ultraviolet laser beam. The liquid solidifies when irradiated, and by using a slowly descending platform and a computer-controlled laser beam, the system can create objects that cannot be created using conventional computer-controlled machine-tool techniques. *See also* 1987 TOOL.

Michael Haase and coworkers at 3M develop laser diodes that emit blue-green light. *See also* 1995 ENER.

James S. Albus [b. Louisville, Kentucky, May 4, 1935], the inventor, and other engineers at the U.S. National Institute of Standards and Technology build the first working model of a Stewart Platform Independent Drive Environmental Robot (SPIDER). SPIDER is a robot crane that is simpler to build and to operate than a standard crane, yet able to lift up to six times its own weight and position it accurately. Although designated a robot because of its use of sensors and camera "eyes," SPIDER is essentially a crane that uses forces directed against themselves instead of a massive counterweight.

→ Transportation

On April 5 the U.S. space shuttle *Atlantis* begins a six-day mission carrying a crew of Jay Apt, Kenneth Cameron, Linda Godwin, Steven Nagel, and Jerry Ross to launch the *Compton Gamma Ray Observatory*. An unscheduled spacewalk, the first for U.S. astronauts since 1985, is required to get the satellite's antenna to open properly. On August 3 *Atlantis* begins its second eight-day mission of the year, crewed by James Adamson, Michael Baker, John Blaha, David Low, and Shannon Lucid. The astronauts perform 22 experiments and launch a communications satellite. On November 24 *Atlantis* begins its first completely nonsecret military flight with a crew of Frederick Gregory, Thomas Hennen, Terence Henricks, Story Musgrave, Mario Runco, Jr., and James Voss. Studies on

this mission reveal that military installations can be seen very well from space, and a satellite is deployed. The shuttle lands early as a result of failure of a navigation unit.

The U.S. space shuttle *Discovery* begins its first military mission under the new nonsecret policy on April 28. Its crew of Guion Bluford, Michael Coats, Blaine Hammond, Jr., Gregory Harbaugh, Richard Hieb, Donald McMonagle, and Charles Veach test detection devices developed for space use. On September 12 *Discovery* begins a five-day mission with a crew of Mark Brown, James Buchli, John Creighton, Charles Gemar, and Kenneth Reightler, Jr. They deploy the *Upper Atmosphere Research Satellite*.

On June 5 astronauts James Bagian, Francis Gaffney, Sidney Gutierrez, Millie Hughes-Fulford, Tamara Jernigan, Bryan O'Connor, and Margaret Seddon begin a ten-day mission in the space shuttle *Columbia*. Using Spacelab for Life Sciences 1, they perform experiments to test human and animal adaptation to space.

Divers in Lake Morey find what are thought to be the remains of *Aunt Sally*, an internal-combustion-powered boat designed by Samuel Morey and built in the late 1820s. *See also* 1826 TRAN.

The Bendix/King Air Transportation Avionics division develops the Traffic Alert and Collision Avoidance System II, which monitors airspace for 40 miles around its location and monitors the position of up to 31 airplanes, ordering evasive action if required.

► Anthropology

John Desmond Clark [b. London, April 10, 1916, d. Oakland, California, February 14, 2002] and Timothy D. White [b. August 24, 1950] find two fossil bones from a humanlike creature who lived 4,000,000 years ago in the Awash River Valley in Ethiopia. *See also* 1994 ANTH.

▲ Archaeology

On November 16 Eric Lawes, using a metal detector, finds at Hoxne in Suffolk, England, the finest Roman hoard ever discovered in Britain. About 200 gold and silver objects, including 19 bracelets, 78 silver spoons, and 29 pieces of jewelry, along with 14,780 coins (mostly silver but many gold and a few bronze) had been carefully wrapped in cloth, packed in wooden boxes, and buried in a field in the very last days of the Roman occupation of Britain (after 407 CE). *See also* 1990 ARCH.

★ Astronomy

John Mather and George Smoot, using NASA's *Cosmic Background Explorer (COBE)* satellite, discover inhomogeneities in the cosmic background radiation. These indicate the existence of small density fluctuations in the period immediately after the big bang that are thought to have been the seeds of galaxies and clusters of galaxies in the early universe. The discovery tends to confirm the big bang with inflation theory of the origin of the universe. *See also* 1990 AST.

The *Extreme Ultraviolet Explor-*

er (EUVE), a satellite that studies the high range of ultraviolet radiation in the universe, is launched on June 7.

On July 7 U.S. satellite *Solar Anomalous and Magnetospheric Particle Explorer (SAMPEX)* is launched to study particles in space, including space dust and the solar wind.

Mars Observer, a U.S. space probe intended to orbit Mars, is launched on September 25. The space probe will be lost on August 21, 1993, as it approaches the planet. *See also* 1993 AST.

The *Magellan* space probe completes mapping 95 percent of the surface of Venus using radar from orbit about the planet.

The James Clerk Maxwell Telescope (JCMT) on Mauna Kea, Hawaii, begins operations. With a steerable dish 15 m (49 ft) in diameter, it is the largest radio telescope that captures submillimeter wavelengths.

↗ Biology

Thomas Gold proposes that bacteria live throughout the top 5 km (3 mi) of Earth's crust. By 1995 this proposal will become accepted as evidence from deep wells is examined and bacteria are always found.

The genome of the variola virus that causes smallpox is sequenced. *See also* 1991 BIO; 1993 BIO.

Edmond H. Fischer and Edwin G. Krebs are awarded the Nobel Prize in physiology or medicine for discovering reversible protein phosphorylation, a biological regulatory mechanism that starts and

stops a variety of cellular functions. *See also* 1955 BIO.

Chemistry

Rudolph A. Marcus [b. Montreal, Canada, July 21, 1923] is awarded the Nobel Prize in chemistry for his mathematical analysis of the oxidation-reduction process, conducted between 1956 and 1965, in which an electron is transferred from one molecule to another.

Communication

On January 6 AT&T announces that it will start selling in May (it turns out to be August) a mass-market videophone for about \$1500. Using compression of signals, the Videophone 2500 can plug into any ordinary telephone jack and transmit and receive a 8.4-cm (3.3-in.) square picture along with the sound to any other Videophone 2500 for the same price per call as sound alone. *See also* 1927 COMM; 1993 COMM.

A digital cellular phone system is introduced in the United States, tripling user capacity and vastly improving sound quality. *See also* 1983 COMM.

In Paris an experimental digital FM transmitter starts operation. *See also* 1986 COMM.

The first websites make their appearance on the World Wide Web. Marc Andreessen [b. New Lisbon, Wisconsin, 1971] and colleagues develop Mosaic, the first popular Web browser, a computer program for locating websites. The National Science Foundation, which had assumed responsibility for the Internet in 1991, awards Network Solutions, Inc. (NSI) control of registration of domain names for the

Internet. *See also* 1991 COMM; 1994 COMM.

Brian W. Coles, working for Westinghouse Underwater Laser Systems and Applied Remote Technology, develops undersea black-and-white cameras that use laser light to illuminate subjects for undersea photography.

Computers

At the First General Conference on Nanotechnology, Ralph Merkle describes computer software developed to design and test machines that have been assembled one molecule at a time. *See also* 1989 TOOL.

Earth science

The Japanese satellite *Geotail* is launched by NASA on July 24. Its mission is to study Earth's magnetosphere. The magnetosphere is that region in space controlled by Earth's magnetic field, which contains extremely tenuous plasmas of both solar and terrestrial origin. A Swedish satellite, *Freja*, is launched using a Chinese rocket from the Gobi Desert; it has a similar mission. *Freja* carries experiments not only from Sweden, but also from the United States, Canada, France, and Germany.

Ecology & the environment

Representatives of 178 countries meet at the Earth Summit in Rio de Janeiro, Brazil, and sign treaties intended to protect biological diversity and halt global warming. *See also* 1990 ECOL; 1995 ECOL.

In New York City the U.S. National Audubon Society rebuilds the interior of a 19th-century department store as

its national headquarters using concepts that are termed "green architecture." All materials used in the rebuilding are renewable or recycled. By reusing an existing structure, the building saves 300 tons of steel, 9000 tons of masonry, and 560 tons of concrete. Other savings come from lighting that adjusts to ambient light and to the presence or absence of people in the room, along with an effective ozone-friendly air-conditioning system that needs only half the capacity ordinarily used for a building of its size. Although costing about 10 percent more to build, the office, by using 61 percent of the heating energy and 68 percent of the electricity of conventional buildings, will repay the extra building costs within five years. *See also* 1987 ECOL.

Electronics

IBM develops the silicon-on-insulator (SOI) bipolar transistor. It can operate at 20 gigahertz, the highest operational frequency achieved to this date with a bipolar transistor. *See also* 1990 ELEC.

Energy

The biggest array of thin-film photovoltaic modules ever assembled starts operation in Davis, California. Built by Advanced Photovoltaic Systems, the 9600 modules convert sunlight into electricity, delivering up to 479 kilowatts, enough for 124 homes. *See also* 1991 ENER.

The Sanyo Electric Company of Japan introduces a kerosene-fueled space heater in which both the speed of the fan and adjustment of heat to match temperature needs are

controlled devices based on chaos theory. This permits temperatures to fluctuate more than in conventional feedback systems, which attempt to maintain a steady state by simply turning the heat and fan simultaneously on or off. *See also* 1961 EAR.

Materials

General Electric reports the synthesis of a three-carat diamond that consists almost entirely of the carbon-13 isotope. The diamond has a higher density and hardness than diamonds found in nature, which contain only about 1 percent of the carbon-13 isotope. *See also* 1991 MATR.

Medicine & health

On January 6 the U.S. Food and Drug Administration asks manufacturers to stop making and doctors to stop installing silicone breast implants until further studies can be done on the safety of the devices. Some believe that leaked silicone causes immune system disorders. *See also* 1960 MED.

On June 28 the liver from a baboon is transplanted into a human whose own liver was destroyed by hepatitis. The operation at the University of Pittsburgh Medical Center appears initially to be a success, but the patient later dies as a result of complications of a pre-existing AIDS condition. *See also* 1963 MED.

The U.S. Food and Drug Administration and the Canadian Department of Health and Welfare approve a powerful anticancer drug made from the bark of Pacific yew trees. The drug is Taxol, also known as paclitaxel, which is especially advantageous in

treating ovarian cancer. *See also* 1971 MED.

The U.S. Food and Drug Administration approves an injectible form of sumatriptan, trade name Imitrex, for treatment of migraine headaches.

U.S. health organizations recommend that infants sleep on their sides or backs to reduce the risk of sudden infant death syndrome (SIDS), a fatal condition of no known cause that affects seemingly healthy infants less than a year old. The campaign will be a success, reducing SIDS deaths dramatically.

The European Patent Office (EPO), five years after U.S. Patent and Trademark Office approval, grants patent EP 169672 to Harvard University for a mouse created by genetic engineering by Philip Leder. The mouse is by now christened the Oncomouse for its sensitivity to carcinogens. Animal rights groups challenge the patent, the first granted by the EPO on an animal. The U.S. Patent and Trademark Office on December 29 issues three more patents for mice with specific transplanted genes — two breeds to mimic human diseases (mice that develop enlarged prostates and mice without immune systems for use in AIDS research) and a strain of mice resistant to viruses for use in developing disease-resistant livestock. *See also* 1988 MED.

❖ Physics

Georges Charpak is awarded the Nobel Prize in physics for his invention of the multiwire electronic detector for high-energy subatomic particles;

this becomes the basic tool used to observe interactions produced by particle accelerators. *See also* 1968 PHY.

I Tools

Conductus, Inc. introduces Mr. SQUID, the first high-temperature superconducting device to become available commercially (a SQUID is a superconducting quantum interference device, used for measuring extremely small currents, voltages, and magnetic fields). Another high-temperature superconducting device that is produced (by Illinois Superconductor Corporation) is a dipstick for measuring the level of very cold fluids, such as liquid nitrogen. *See also* 1988 MATR.

Fred Wellstood invents the scanning SQUID microscope.

A company in France develops an aerosol can in which a small solenoid produces the aerosol electrically, thus eliminating the need of a gas propellant. *See also* 1941 MATR.

→ Transportation

On January 22 the U.S. space shuttle *Discovery* is launched with a crew of Ronald Grabe, Stephen Oswald, Norman Thagard, William Readdy, David Hilmers, Roberta Bondar, and Ulf Merbold. They operate the International Microgravity Laboratory-1 on an eight-day mission. On December 2 *Discovery* is launched on a military mission to deploy a secret satellite. The crew consists of Guion Bluford, Jr., Robert Cabana, Michael Clifford, James Voss, and David Walker.

On March 24 *Atlantis* is launched with a mission of conducting atmospheric and

auroral studies. The crew is Charles Bolden, Brian Duffy, David Leestma, Byron Lichtenberg, Kathryn Sullivan, Michael Foale (U.K.), and Dirk Frimout (Belgium). On July 31 *Atlantis* flies again, with a crew of Andrew Allen, Franklin Chang-Diaz, Jeffrey Hoffman, Marsha Ivins, and Franco Malerba (Italy). The astronauts deploy the *European Retrievable Carrier* (*Eureca*) satellite.

On May 7 the space shuttle *Endeavour* makes its maiden flight carrying astronauts Thomas Akers, Daniel Brandenstein, Kevin Chilton, Richard Hieb, Bruce Melnick, Kathryn Thornton, and Pierre Thout. They rescue the erring *Intelsat 6* communications satellite and deploy it into its proper orbit. On September 12 the *Endeavour*'s second mission is launched with a crew of Jay Apt, Curtis Brown, Jr., Robert Gibson, Mae Jemison (the first black woman in space), Mark Lee and Jan David (the first married couple to travel together into space), and Mamoru Mohri (Japan). They study the effects of low gravity on humans and other animals.

On June 25 the *Columbia* carries astronauts Ellen Baker, Kenneth Bowersox, Lawrence DeLucas, Bonnie Dunbar, Carl Meade, Richard Richards, and Eugene Trinh into space along with the U.S. Microgravity Laboratory-1 (the International Microgravity Laboratory was on an earlier flight this year). On October 22 *Columbia* is again launched, this time with a crew of Michael Baker, Tamara Jernigan, William Shepherd, Charles Veach, James Wetherbee, and Steven MacLean (Canada).

They deploy Italy's *Laser Geodynamic Satellite-II*.

Russian cosmonauts take part in extended missions to the *Mir* space station. On March 17 the *Soyuz TM 14* brings Aleksander Kaleri, Aleksander Viktorenko, and Klaus-Dietrich Flade (Germany) to *Mir*. Flade returns aboard *Soyuz TM 13*. The next trip up begins on July 27 on *Soyuz TM 15*. Sergei Avdeyev, Anatoli Solovyov, and Michel Tognini (France) are the crew going up. Tognini returns on August 10 aboard *Soyuz TM 14*.

1993

◀ Anthropology

Meave Leakey and Alan Walker discover fossils in the Lake Turkana region of Kenya that they identify as a new species of early hominid. They name it *Australopithecus anamensis* ("australopithecine from the lake"). The fossils date from about 4,200,000 years BP. *See also* 1983 ANTH.

★ Astronomy

Images from the space probe *Galileo* reveal the first known satellite of an asteroid, which orbits the asteroid 243 Ida. The small satellite is named Dactyl. *See also* 1991 AST; 1995 AST.

On February 20 the Japanese satellite *ASCA* (a.k.a. *Astro D*) is launched. It is a space-based X-ray telescope. *See also* 1990 AST.

In May the Keck I telescope on the island of Hawaii begins regular operation, becoming the largest optical telescope. Its mirror consists of 36 segments, each 1.8 m (6 ft)

across. *See also* 1948 AST; 1996 AST.

On December 2 astronauts Thomas Akers, Kenneth Bowersox, Richard Covey, Jeffrey Hoffman, Story Musgrave, Kathryn Thornton, and Claude Nicollier (from Switzerland) are launched on the space shuttle *Endeavour*. In space, they successfully retrieve the *Hubble Space Telescope* (*HST*) and install a corrective lens for the main mirror, which has a serious defect. They then relaunch *HST*, where it functions as originally intended. *See also* 1990 AST.

On May 29 radio astronomers begin observing with the complete Very Long Baseline Array (VLBA), also known as the U.S. National Radio Astronomy Observatory. A network of ten radio telescopes at widely separated locations uses interferometry to achieve angular resolutions 500 times better than the finest optical telescopes. The sites, all in the United States, range from the Virgin Islands to Hawaii. Each has a steerable dish antenna that is 25 m (82 ft) in diameter. The baseline extends about 8600 km (5000 mi), giving a resolution equal to reading newspaper type from 5000 km (3000 mi) away. Parts of the VLBA had been in operation since 1986. *See also* 1980 AST; 1997 AST.

Russell Hulse and Joseph Taylor are awarded the Nobel Prize in physics for their discovery in 1974 of the first binary pulsar, which furnished indirect proof of the existence of gravity waves. *See also* 1974 AST.

Biology

The Ebola virus genome is

sequenced. *See also* 1992 BIO; 1995 BIO.

Vu Van Dung, John MacKinnon, and coworkers announce the identification from recent horns and skins of the "Vu Quang bovid." A large goatlike mammal from the forests of Vietnam, it replaces the kouprey, found in Vietnam in 1937, as the most recently discovered large mammal, weighing about 100 kg (220 lb). The Vu Quang bovid is later recognized by its native name of saola (a.k.a. forest goat) and given the scientific name *Pseudoryx nghetinhensis*. *See also* 1994 BIO.

Richard Roberts and Phillip Sharp are awarded the Nobel Prize in physiology or medicine for discovering "split genes"; genes in many organisms are not unbroken strands of DNA but instead are fragmented by stretches of unrelated DNA (these noncoding segments are now called introns). *See also* 1977 BIO.

Chemistry

Kary Mullis is a cowinner of the Nobel Prize in chemistry for developing polymerase chain reaction (PCR) in 1983, a technique for making millions of copies of a specified fragment of DNA. The other winner is Michael Smith [b. Blackpool, England, April 26, 1932, d. Vancouver, Canada, October 4, 2000] for development of an oligonucleotide-based, site-directed mutagenesis, which is used to alter specific coding sites on DNA. *See also* 1983 BIO.

Communication

In a demonstration on January 28 of the first system for telephonic simultaneous translation, Japanese researcher

Toshiyuki Takezawa speaks the word "Moshimoshi" in Kyoto; his word is translated into Japanese text by one computer, which then passes it on to another computer that translates it into English text and sends it via a modem and telephone lines to Pittsburgh, Pennsylvania, where yet another computer reads the text and synthesizes the English word "Hello"; the process takes 12 seconds.

In response to a rival picture-transmitting telephone from MCI Communications, AT&T announces that it will cut the price of its Videophone 2500 from \$1500 to \$1000 a set. MCI sells its version for \$750. *See also* 1927 COMM; 1992 COMM.

In the United States, FM radio stations begin to use a system already in place in Europe to transmit digital data along with the signal used to produce sound. The radio data system (RDS) is used to transmit messages that appear on a small display screen and for such purposes as replacing checks on the U.S. emergency broadcasting system. *See also* 1986 COMM.

Computers

A team led by Harry Jordan and Vincent Heuring at the University of Colorado unveils on January 12 the first general-purpose all-optical computer capable of being programmed and manipulating instructions internally. *See also* 1990 ELEC.

The Apple IIe, last in the upgrades of the Apple II computer to be manufactured, goes out of production in November. The first Apple II had been displayed in April 1977.

Apple introduces the Newton, the first version of the first personal digital assistant (PDA). It is not very successful.

Earth science

Ice cores from Greenland and from Antarctica reveal the record of Earth's climate for the past 250,000 years.

Weather scientists discover unexpected, but short-lived, displays of electromagnetism in Earth's upper atmosphere above thunderstorms. These are termed sprites, blue jets, and ELVES.

Ecology & the environment

On February 9 the Brazilian satellite *Pegasus 3* is launched by Orbital Sciences Corporation of Fairfax, Virginia. The mission of the satellite is to study changes in the environment of the Amazon basin.

The U.S. Department of the Interior announces a National Biological Survey to catalog all of the estimated 650,000 species living in the United States and describe their living conditions.

Electronics

Shuji Nakamura develops the first blue light-emitting diode (LED) suitable for commercial applications. He had developed his first blue LED two years earlier, making the highest crystal quality attained to that time. *See also* 1990 ELEC; 1995 ENER.

Fujitsu in Japan introduces a 256-megabit memory chip. *See also* 1991 ELEC.

Intel Corp announces on March 22 that it is shipping its Pentium microprocessor to computer manufacturers.

Pentium is the fifth generation of the basic chip that powers IBM computers and their clones. The Pentium chip contains 3,100,000 transistors and operates twice as fast as the best fourth-generation Intel chip, the 486DX2. *See also* 1990 ELEC.

II Food & agriculture

Calgene Inc. announces that it will apply for food-additive status from the U.S. Food and Drug Administration (FDA) for the marker gene, known as *kan'r*, in its genetically altered tomato termed the Flavr Savr. The Flavr Savr will be approved by the FDA in 1994, but it will not become a commercial success and will be taken off the market in mid-1996. *See also* 1980 BIO; 2000 FOOD.

In Iraq the Third River Canal between the Tigris and Euphrates is completed, primarily to provide water to wash salt out of the soil, salt that had been introduced by irrigation practices of the past; it would also drain large areas of marshland, making them suitable for conventional farming. The canal runs from Mahmudiya, near Baghdad, to Basra on the Persian Gulf, a distance of 560 km (350 mi). *See also* 1258 FOOD.

♦ Materials

A team of scientists from Catalytica Inc. in Mountain View, California, announces that they have discovered a way to make methanol from methane that is cheap and that works at a low temperature. The input is methane and air, catalyzed by ionized mercury, and the products are methanol and carbon dioxide. *See also* 1928 MATR.

Scientists at Harvard create a thin film of a carbon-nitrogen

compound that is believed to be harder than diamond. In another approach, Patricia Bianconi and student Glenn Visscher produce a diamond-like film from a polyacetylene plastic.

Σ Mathematics

Andrew Wiles provides a first proof of Fermat's "Last Theorem," the statement that for $n > 2$ and nonzero integral a , b , and c , there is no true statement of the form $a^n + b^n = c^n$. *See also* 1988 MATH; 1995 MATH.

♥ Medicine & health

Susan Perrine and coworkers discover that administration of butyrate, a naturally occurring fatty acid, can successfully treat anemias caused by deformed hemoglobin, such as sickle cell anemia. Butyrate in the bloodstream promotes the development of fetal-type hemoglobin, which, because the fetal type is directed by different genes from adult hemoglobin, is not affected by genetic diseases of normal hemoglobin. *See also* 1934 MED.

Apple Computer becomes the first company to offer a split computer keyboard for reduction of repetitive stress hand injuries such as carpal tunnel syndrome. The keyboard has been designed without reference to an earlier version patented by Tony Hodges, according to Apple. *See also* 1986 MED.

Yvonne Bryson, Steven Miles, Erin Balden, and coworkers announce development of a fast and effective way to detect AIDS in newborns and infants. AIDS may be contracted in the womb, which can be detected at birth, or

Andrew Wiles

[b. Cambridge, England, April 11, 1953]

When he was ten years old, Wiles became interested in the solution to the problem known as Fermat's Last Theorem. Although he worked on other parts of mathematics while obtaining his doctorate at Cambridge University in 1980, he remained interested in the Fermat theorem. He began teaching mathematics at Princeton University in New Jersey in 1982. In 1986 he learned of new results that might lead to a proof of the Fermat theorem and began a secret project to use this approach to make a proof. It took seven years of intense concentration to produce a proof, but other mathematicians pointed out flaws in the 1993 publication. In collaboration with Richard L. Taylor, Wiles resolved all the difficulties and published the final proof in 1995.

during birth, which before the new test could not be determined until four to six weeks later.

Scientists recognize a newly found disease, hantavirus pulmonary syndrome, which kills several Americans who have become infected from contact with dust infected by rodent dung.

The U.S. Environmental Protection Agency declares that environmental tobacco smoke, known as second-hand smoke, is a lung carcinogen and poses a serious respiratory problem for infants and young children. *See also* 1988 MED.

Adam Software Inc. announces on April 7 the availability of its CD-ROM called Animated Dissection of Anatomy for Medicine (ADAM), a virtual reality version of a cadaver. It is complete with all the organs that could be virtually dissected by a medical student. *See also* 1832 MED.

A review of twin and adoption studies indicates that there is a significant genetic component in homosexuality.

✿ Physics

Colossal magnetoresistance (more powerful than the pre-

viously known giant magnetoresistance), the phenomenon that electrical resistance in certain metallic multilayers changes over a factor of ten when placed in a magnetic field, is discovered. *See also* 1988 PHY.

I Tools

The NIST-7 atomic clock, based on laser beams that guide streams of atoms, becomes the most accurate clock ever made; the new clock, based on the standard of 9,192,631,770 vibrations of a cesium atom as the measure of a second, is calculated to stay within 1 second of accuracy per 3,000,000 years of operation. *See also* 1989 PHY.

↗ Transportation

Early in the year scientists from MIT launch in Antarctic waters the inexpensive tetherless (autonomous) robot submersible *Odyssey*, designed by James G. Bellingham and coworkers. The 2-m (7-ft) robot can to dive to ocean depths as great as 5 km (3 mi). Because *Odyssey* costs about a hundredth as much as the first significant robot submersible, *Jason*, and a thousandth as much as the human-piloted *Alvin*, it is thought to inaugurate a new era of cheap robots.

for undersea exploration. *See also* 1962 TOOL.

In March a team from the Woods Hole Oceanographic Institution launches off Bermuda the *Autonomous Benthic Explorer (ABE)*, a tetherless robot submersible designed to sink to ocean depths as great as 6 km (4 mi) and stay there for as long as a year if needed, observing for scientists on the ocean's surface. The 2-m (6-ft) *ABE* was designed by Albert M. Bradley and coworkers. *See also* 1962 TOOL.

1994

► Anthropology

Gen Suwa of the University of Tokyo discovers the first fossil of *Ardipithecus ramidus* at Aramis, Ethiopia, at this time the oldest known hominid. *A. ramidus* lived 4,400,000 years BP in woodlands mixed with patches of savanna rather than in the true savanna, which previously had been thought to have been the place where early ancestors of humans first developed. *See also* 1992 ANTH; 2001 ANTH.

★ Astronomy

Comet Shoemaker-Levy 9, broken into 21 large fragments, slams into the far side of Jupiter in July, causing fireballs and persistent storms on that planet and permitting scientists on Earth to determine some characteristics of Jupiter's atmosphere.

At the U.S. National Observatory on Kitt Peak in Arizona, the 3.5-m (128-in.) WIYN telescope uses computerized adjustments to its mirror to produce unusually sharp images.



COMET SHOEMAKER-LEVY As the comet first approached Jupiter, the gravitational force of the giant planet broke up the loose aggregation of ice and dust into pieces, which stretched out in a line along the comet's orbit, as shown here. On its next orbit, the comet plunged into Jupiter's atmosphere as more than 21 separate events, producing a series of major explosions visible to the *Galileo* and *Voyager 2* spacecraft with effects also observable by the *Hubble Space Telescope*, although the initial entry took place on the far side of Jupiter from Earth.

On January 25 the joint U.S. military and science satellite *Clementine* is launched to map the Moon from lunar orbit. Later it is supposed to visit the asteroid 1620 Geographos, but a malfunction terminates that portion of the mission. *See also* 1996 AST.

On November 1 the satellite *WIND* is launched into a figure-8 orbit around Earth and the Moon, where it studies the solar wind. *See also* 1996 AST.

The Baikal Neutrino Station (NT-200), a.k.a. Baikal Deep Underwater Neutrino Telescope (BDUNT), begins operations in Lake Baikal, Russia. It features underwater detectors at a depth of 1200 m (4000 ft) that monitor about

1,000,000 m³ (35,000,000 cu ft) of water for Cerenkov radiation (flashes of light) caused when neutrinos collide with atoms and produce muons that move faster than the speed of light in water. *See also* 2000 AST.

❖ Biology

Three new species of large mammal are captured alive for the first time. One is the saola, or forest goat, from Vietnam, identified just the previous year. Also from the Vietnamese forest, scientists locate the first live specimens of the giant muntjac, or barking deer. The third newly captured mammal, from New Guinea, is the black-and-white tree kangaroo, known previously only from a photograph. *See also* 1993 BIO.

Alfred G. Gilman [b. New Haven, Connecticut, July 1, 1941] and Martin Rodbell [b. Baltimore, Maryland, December 1, 1925, d. December 7, 1998] are awarded the Nobel Prize in physiology or medicine for discovering G-proteins, chemicals that help cells convert extracellular signals into cascades of internal reactions by which cells grow, differentiate, and perform other essential life processes.

▷ Chemistry

Peter Armbruster and Sigurd Hofmann at the Gesellschaft fuer Schwerionenforschung (GSI) in Darmstadt, Germany, announce the creation of a few atoms each of element 110 and element 111. In 2003 element 110 will be officially named darmstadtium (Ds).

George A. Olah [b. Budapest, Hungary, May 22, 1927] is awarded the Nobel Prize in

chemistry for his use of superacids and cryogenics to create and stabilize carbocations, important fragments of hydrocarbons that normally occur in the creation of fuels and other chemicals from crude oil, but which could not be studied without the techniques developed by Olah in the early 1960s.

☛ Communication

A group of more than a hundred software producers, including IBM, Microsoft, and Sun Microsystems, form the World Wide Web Consortium to maintain and set standards for use of the system devised in 1990 by Tim Berners-Lee, who is installed as director of the consortium. *See also* 1991 COMM.

Sun Microsystems introduces JAVA, which takes its name from a slang term for coffee, a staple part of programmers' diets. JAVA is the first universal software language — the same program will run on any computer platform, including Windows, Macintosh, and UNIX.

▀ Computers

Leonard Adleman demonstrates a biological computer based on DNA that can solve a difficult problem in mathematics. PCR is used to extract the solution to the problem from the DNA.

Apple introduces the first personal computer to use the Power PC RISC chip, the PowerMac.

⊕ Earth science

Seismology reveals that the boundary between Earth's outer core and the mantle is not smooth but is covered with

hills and valleys, some as much as 6 km (3.5 mi) high or deep.

Ecology & the environment

Two species are removed from the U.S. Endangered Species List: the Arctic peregrine falcon (*Falco peregrinus tundrius*) and the gray whale (*Eschrichtius robustus*). The falcon population had declined rapidly after the introduction of DDT, which caused reproductive failure through eggshell thinning, but began recovery after DDT was banned in the early 1970s. The gray whale had twice been hunted to the edge of extinction, first in the 1850s and again in the early 1900s, but was given protected status in 1947 and slowly recovered its Pacific population, although the Atlantic population is now extinct. *See also* 1987 ECOL; 1995 ECOL.

Mathematics

Peter Shor [b. August 14, 1959] of AT&T Labs devises the first algorithm for factoring large numbers that would use a hypothetical quantum computer. With a quantum computer, the algorithm would solve such problems in a manageable amount of time (known as polynomial time) even for numbers expressed with a very large number of digits. *See also* 1996 COMP.

Medicine & health

Many people in Hungary are stricken with lead poisoning when a manufacturer uses the red oxide of lead called minium to improve the color of paprika. *See also* 1991 ECOL.

Physics

Bertram N. Brockhouse [b. Lethbridge, Alberta, Canada,

July 15, 1918] and Clifford D. Shull [b. Pittsburgh, Pennsylvania, September 23, 1915, d. Medford, Massachusetts, March 31, 2001] are awarded the Nobel Prize in physics for their use of neutron scattering to determine atomic structure.

I Tools

Charles K. Rhodes of the University of Chicago develops an X-ray-emitting laser based on exposing xenon clusters to ultraviolet laser light; this produces a burst of hard X rays. *See also* 1988 TOOL.

Transportation

The Russian space program continues its series of extended missions aboard *Mir*. On January 8 *Soyuz TM 18* lifts up to *Mir* carrying Viktor Afanasyev, Valeri Polyakov, and Yuri Usachyov. Polyakov returns aboard *Soyuz TM 20* while the others return on July 9. July 1 brings *Soyuz TM 19* carrying Yuri Malenchenko and Talgat Musabayev, who return November 4. The October 3 mission is on *Soyuz TM 20* with Yelena Kondakova, Alexander Viktorenko, and Ulf Merbold (of the European Space Agency). Merbold returns aboard *Soyuz TM 19* while the others descend on March 22, 1995.

The U.S. space shuttle *Discovery* is launched February 3 carrying Charles Bolden, Jr., Franklin Chang-Diaz, Jan Davis, Kenneth Reightler, Jr., Ronald Sega, and Sergei Krikalev (the first Russian to fly aboard the U.S. shuttle). It fails in an attempt to deploy the Wake Shield Facility for growing semiconductors. On September 9 *Discovery* returns to space with Blaine Hammond, Jr., Susan Helms, Mark

Lee, J.M. Linenger, Carl Meade, and Richard Richards, who release and recover an astronomical satellite. The crew also uses an instrument to study Earth's atmosphere.

Columbia is launched on March 4 with a crew of Andrew Allen, John Caspar, Charles Gemar, Marsha Ivins, and Pierre Thuot. The crew tests technologies that will be needed for construction of the International Space Station (ISS). On July 8 *Columbia* is again launched, this time with Robert Cabana, Leroy Chiao, James Halsell, Jr., Richard Hieb, Donald Thomas, Carl Walz, and Chiaki Naito-Mukai (Japan's first female astronaut) aboard. They study the effects of microgravity on a variety of living organisms.

Endeavour flies on April 9 with Jay Apt, Kevin Chilton, Michael Clifford, Linda Godwin, Sidney Guitierrez, and Thomas Jones. It carries the Space Radar Laboratory (SRL-1), which scans about 12 percent of Earth's surface. On September 30 *Endeavour*'s crew consists of Michael Baker, Daniel Bursch, Thomas Jones, Steven Smith, Terrence Wilcutt, and Peter Wisoff. This is the second flight of Space Radar Laboratory (SRL-2), which scans for changes in Earth sites monitored in the April mission.

Atlantis is launched on November 3 with a crew of Curtis Brown, Donald McMonagle, Scott Parazynski, Joseph Tanner, and Jean-François Clervoy (of the European Space Agency). They study environmental changes on Earth.

The 50-km- (30-mi-) long Eurotunnel (a.k.a. the Channel, Jr., Susan Helms, Mark

nel is opened, linking France and the United Kingdom. *See also* 1990 TRAN.

1995

► Anthropology

Because of concerns that roots or animals may be damaging them, one section of the fossil footprints at Laetoli, Tanzania, of three *Australopithecus afarensis* individuals are excavated, photographed, and carefully mapped, then reburied in sand. The same treatment will be given to the other section in 1996. *See also* 1979 ANTH.

★ Astronomy

Swiss astronomers Didier Queloz [b. February 23 1966] and Michel Mayor [b. Lausanne, Switzerland, January 12, 1942] discover a planet half the mass of Jupiter orbiting the star 51 Pegasi at a distance of 50 light-years. This is the first known planet orbiting an ordinary star other than the Sun (such planets later will be known as extrasolar planets or as exoplanets). *See also* 1987 AST; 1997 AST.

The *Hubble Space Telescope* photographs giant pillars in the Eagle Nebula that are thought to be 1,000,000,000,000 km (6,000,000,000,000 mi) high.

The Giant Meterwave Radio Telescope is installed north of Pune, India. It contains 30 parabolic 45-m (148-ft) antennas arranged in a 25-km (15-mi) Y, which are combined with radio interferometry.

In the Creighton Mine at Sudbury, Ontario, astronomers begin operations of the Sudbury Neutrino Observatory, which employs 9600 photo-multiplier tubes embedded in

Measuring with waves, seeing with fringes

Possibly the most accurate form of measure is based on the interaction of one wave with another. The principles involved are the same whether the waves are of water, light, or sound. If two waves are exactly the same, they can be adjusted so that they either cancel each other or double the combined amplitude. If the crests of one version of the wave are superimposed on the troughs of the other, the waves will cancel. If they are light waves, this will produce darkness. If the crests of one version of the wave are superimposed on the crests of another version, the waves will add. If they are light waves, the result will be brighter light (brightness indicates amplitude for light). If the waves are not exactly the same, superimposing them will produce bands of brightness and darkness, called an interference pattern. Using an interference pattern to make measurements is called interferometry.

Among the first to use interferometry in measurement was Albert Michelson in 1881. By 1887 he and Edward Morley had used the idea to conduct one of the most famous experiments in science. They established through experimental data that the velocity of light is not affected by the movement of Earth through space. This result helped make people accept Einstein's theory of relativity, which included the concept that the velocity of light in a vacuum is a universal constant.

Astronomers, starting with Martin Ryle in the 1960s, use interferometry with radio telescopes to create giant, fictitious telescopes that work better than real ones. Two or more telescopes some distance apart (called the baseline) acting together as a single telescope can be used to obtain better resolution than any one telescope by extracting data from the interference fringes between the waves that have taken two slightly different paths.

At first, Ryle used just two radio telescopes that were not very far apart. By 1980, the Very Large Array in Socorro, New Mexico, was using 27 radio telescopes linked by computer to obtain the same resolution obtainable from a single radio telescope 27.4 km (17 mi) in diameter. Today, with interferometry, a group of telescopes all over Earth can be linked by satellite and computer to give the equivalent of a single telescope with the diameter of the planet; this is the method used in the Very Long Baseline Array. Astronomers also use space-based radio telescopes that allow a baseline that exceeds the size of Earth.

Starting in 1974, astronomers began to experiment with combining light waves, which are much shorter than radio waves, in optical interferometry. The principles are the same as in radio interferometry, but the required precision is much greater and much shorter baselines are used. The first actual success came in 1995. Telescopes with giant mirrors that are close to each other, such as the Keck twins on Hawaii and the four-telescope Very Large Telescope at Cerro Paranal, Chile, can and do use optical interferometry for their best resolution. Because the atmosphere causes some distortions that cannot be eliminated, optical interferometry is planned for a two-reflector space telescope, the Space Interferometry Mission (SIM), that is scheduled for launch in 2009.

Today, interferometry is the king of measurement systems. Interferometry is so sensitive that it can detect the movement of an object that moves only a centimeter in hundreds of years. It can even be used to determine the rotation of distant stars. Using lasers as the source of light, interferometry can detect tiny movements in the crust of Earth that precede earthquakes.

The interferometer is also the instrument of choice for determining small distances. It can detect tiny variations in thickness of a lens, for example. Using lasers or radar and interferometry combined, space vehicles guide themselves with extreme precision as they cross the vast distances between planets.

1000 metric tons (1100 short tons) of heavy water. The object is to observe Cerenkov radiation produced by muons traveling faster than the speed of light in the heavy water. The use of heavy water allows detection of all three types of neutrinos (electron, muon, and tauon).

COAST (Cambridge Optical Aperture Synthesis Telescope), a combination of four telescopes (a fifth will be added later), makes its first images, the first astronomical images

with high resolution obtained with optical interferometry. *See also* 1988 AST.

In July the *Galileo* space probe, in orbit about Jupiter, drops a capsule onto the giant planet to analyze the composition of its atmosphere. It descends through the atmosphere on December 7, measuring pressure and abundance of helium and hydrogen. The main surprise is that there is no evidence of clouds, although abundant clouds are observed from Earth; scientists think

that the probe simply passes through a cloudless region. Wind speeds reach 720 km (450 mi) per hour. *See also* 1993 AST; 1998 AST.

On March 18 the Japanese satellite *Infrared Telescope in Space* (IRTS) is launched. It operates successfully for 28 days. The European Space Agency's *Infrared Space Observatory* (ISO) is launched on November 17. It extends the work of the earlier space-based observatory *IRAS*. The

ISO is nicknamed Europe's Hubble. *See also* 1983 AST.

On December 2 the European Space Agency and U.S. satellite the *Solar and Heliospheric Observatory* (SOHO), which was built in Europe, is launched by NASA. It studies the Sun from an orbit about 1,500,000 million km (930,000 mi) from Earth, circling close to the L1 Lagrangian point. This gives the satellite a completely unobstructed view of the Sun at all times. *See also* 2001 AST.

Craig Venter

[b. Salt Lake City, Utah, October 14, 1946]

Venter developed a method of deciphering genomes known as whole-genome shotgun sequencing. The genome to be analyzed is broken into random, overlapping fragments of DNA that are a few thousand letters in length. Each fragment is sequenced, or read. Then the fragments are reassembled by a computer into their correct order. Although there were initially many skeptics, Venter's conviction that shotgunning would be faster and just as accurate for much genome deciphering proved to be true, and the technique is now widely used. In 1995 Venter and his team used the technique to obtain the first complete genome (DNA sequence) of an organism other than a virus, that of the bacterium *Haemophilus influenzae*. In 2000, in collaboration with researchers at the University of California at Berkeley, he published almost the entire genome of the fruit fly *Drosophila melanogaster*. In 2001 his team and a competing group published rough drafts of the human genome.

On December 30 the United States launches its first X-ray telescope since the *Einstein Observatory*, the *Rossi X-Ray Timing Explorer (XTE)*. It studies X-ray sources in the Milky Way Galaxy, including stars, pulsars, and black holes. *See also* 1978 AST; 1999 AST.

Biology

A team lead by Craig Venter publishes the first complete sequencing of the entire genome of a free-living organism, *Haemophilus influenzae*. Previous successes had all come with sequencing the genomes of viruses. *See also* 1997 BIO.

In December Danish scientists Peter Funch [b. Copenhagen, November 10, 1965] and Reinhardt M. Kristensen [b. December 6, 1948] announce the discovery of a microscopic animal that lives attached to the mouthparts of the Norwegian lobster. They name it *Symbion pandora* and, because it is so different from other animals (for one thing, its cilia-ringed mouth is adjacent to its similarly ringed anus), they recommend it be classified in a new phylum, *Cycliophora*.

Edward B. Lewis [b. Wilkes-Barre, Pennsylvania, May 20, 1918], Christiane Nüsslein-Volhard [b. Magdeburg, Germany, October 20, 1942], and Eric F.

Wieschaus [b. South Bend, Indiana, June 8, 1947] are awarded the Nobel Prize in physiology or medicine for identifying the genes that guide embryonic development in fruit flies (*Drosophila melanogaster*).

Communication

In August a group of physicists at the University of Oregon report an exceptionally high data-storage density of 8 gigabits per square inch. By using a laser beam containing data in the form of different frequencies, they store data as patterns of excited atoms in a frequency-sensitive medium. This medium is a YAG crystal containing thulium atoms for storing the data, and a commercial GaAlAs diode laser is used for writing the data in the material.

Competing groups agree on standards for the DVD (then known as the digital video disk; later its name will be changed to digital versatile disk).

Earth science

Various teams of geologists studying North America recognize that large regions of the west coast of the continent, called terranes, were originally small landmasses in the Pacific Ocean that had been moved by plate tectonics

and pasted onto the continent. *See also* 1987 EAR.

James Cochran and coworkers at Lamont-Doherty Earth Observatory establish that India and Australia are on two partly separated plates rather than on one as previously believed. *See also* 1963 EAR.

Scientists from the American Museum of Natural History discover that a fossil previously brought back from the Gobi Desert is of a dinosaur brooding a nest of eggs. *See also* 1926 ANTH.

Ecology & the environment

The United Nations Working Group I of the Intergovernmental Panel on Climate Change reports that "the balance of evidence suggests that there is a discernable human influence on global climate." The report makes it clear that that influence can be characterized as global warming. *See also* 1992 ECOL; 1997 ECOL.

Three species of kangaroo, the eastern gray, the western gray, and the red, are removed from the Endangered Species List because of population recovery. *See also* 1994 ECOL; 2001 ECOL.

F. Sherwood Rowland, Mario Molina, and Paul Crutzen [b. Amsterdam, December 3,

1933] are awarded the Nobel Prize in chemistry for the recognition of chemical pathways that chlorofluorocarbons take in the upper atmosphere that destroy the ozone layer, permitting additional harmful ultraviolet radiation to reach Earth's surface. *See also* 1974 ECOL.

Energy

Shoji Nakamura and coworkers at Nichia Chemical Industries in Japan develop blue-light laser diodes that have lifetimes of several dozen hours, too short for most commercial applications but capable of being improved. Later versions will become standard for DVDs, where their short wavelength makes them able to read and write smaller dots. *See also* 1991 ENER.

Junji Kido of Yamagata University in Japan and coworkers combine three different diode layers, including a blue-light-emitting diode the group invented, to create white light.

Mathematics

Andrew Wiles publishes a corrected version of his 1993 proof of Fermat's "Last Theorem." *See also* 1993 MATH.

Jonathan and Peter Borwein calculate π up to 10,000,000,000 decimal places. *See also* 1987 MATH; 1999 MATH.

Medicine & health

R. Sherrington, Peter H. St. George-Hyslop, Gerald D. Schellenberg, and many colleagues isolate and characterize two genes responsible for early-onset, familial Alzheimer's disease. *See also* 1907 MED.

The FDA approves alprostadil

(Caverject), the first drug for treatment of male impotence. It must be injected into the penis. *See also* 1998 MED.

❖ Physics

Eric A. Cornell [b. Palo Alto, California, December 19, 1961] and Carl Wieman [b. Corvallis, Oregon, March 26, 1951] create a new form of matter: a Bose-Einstein condensate (BEC) of about 2000 rubidium atoms at 20 nK (nanoKelvins) — that is $0.00000002^{\circ}\text{C}$ ($0.00000036^{\circ}\text{F}$) above absolute zero — that behave as a single “superatom.” A few months later Wolfgang Ketterle [b. Heidelberg, Germany, October 21, 1957] creates a Bose-Einstein conden-

sate with sodium atoms. *See also* 1924 PHY; 1997 PHY.

Edward Witten [b. Baltimore, Maryland, August 26, 1951] and Paul Townsend separately introduce a superstring theory as a limit of 11-dimensional supergravity theory with quantized membranes, an idea that becomes the start of M theory and branes. M theory and brane theory begin with the concept of membranes in 11-dimensional space as the fundamental entities of reality but becomes more abstract. Many physicists feel that these theories are the true bases of physics. *See also* 1984 PHY.

Nine antihydrogen atoms are obtained at CERN by Walter Oelert and his team. Xenon

atoms are fired at an antiproton beam, creating electron positron pairs, whereby the positrons combine with the antiprotons, forming antihydrogen atoms. These move too swiftly to be analyzed for properties, however. *See also* 1934 PHY; 2002 PHY.

The top quark is observed at Fermilab near Chicago; it is produced by colliding protons and antiprotons. The top is the last of the predicted six quarks to be found. *See also* 1977 PHY.

Martin Perl is awarded a share of the Nobel Prize in physics for his discovery of the unpredicted tau particle (a heavier version of the electron and muon). Frederick Reines is the

cowinner of the prize for the first observation of the neutrino (with Clyde Cowan, who died before the prize was awarded). The neutrino had been accepted as existing since 1930, but it interacts so little with matter that no one had been able to detect it before Reines and Cowan. *See also* 1977 PHY; 1956 PHY.

I Tools

The Monopole Astrophysics Cosmic Ray Observatory (MACRO) starts operation in the Gran Sasso tunnel at Abruzzo, Italy. Some $10,000 \text{ m}^2$ (1308,000 sq ft) of detectors are used in the search of magnetic monopoles as well as other particles, including cosmic rays and neutrinos.

Spin — not just for politicians

Atoms, like subatomic particles, possess spin. Although spin behaves mathematically as its name suggests — possessing rotational angular momentum like a spinning object — spin is really a quantum quality closely related to magnetism. Because spin is a quantum phenomenon, it occurs in discrete steps. Because it is related to magnetism, it exists in two ways, just as a magnet has a north and a south pole.

Spin is fundamental to how particles behave. Spin is represented by a number, which can either be a half integer or an integer (whole number). Half-integer spin defines the particle as a fermion, such as an electron or quark, while integral spin makes the particle a boson, such as a photon or pion. Fermions cannot be in the same place at the same time, but bosons overlap easily with each other, taking part in collective action — behavior similar to that of light, which consists of photons. Any number of photons can be in the same state at once — for example, in a laser. Subatomic particles of matter all have half-integer spins, including the elemental particles such as electrons, quarks, and neutrinos. The particles that carry forces, such as photons, pions, and gluons, have integral spins.

Composite particles such as protons and neutrons are also divided into bosons and fermions, as are composite systems such

as atoms and molecules. Neutrons and protons are fermions because they contain an odd number of quarks — each has three quarks, giving them a half-integer spin. Similarly, the pion is composed of two quarks, making for integral spin.

If the total number of neutrons, protons, and electrons in an atom is odd, then the atom is a fermion; if this total is even then the atom is a boson. For example, helium-3 atoms are fermions, while helium-4 atoms are bosons. Spin properties of atoms are usually not noticeable in macroscopic samples because their normal motion causes spin states to become mixed. Bosonic behavior was calculated by Satyendra Bose and Albert Einstein. Einstein predicted that very cold atoms with even spins could condense into a new form of matter, now called a Bose-Einstein condensate (BEC).

The first Bose-Einstein condensates were created in 1995 by containing a dilute gas of bosonic rubidium or other bosonic atoms in a magnetic trap and cooling it. The result is a state of matter for which all the individual atoms occupy a single, lowest quantum state and become indistinguishable — forming a “superatom.” Because atoms in a BEC behave like photons emerging from a laser, devices similar to lasers that use atoms instead of light are possible. The practical consequences of such devices are as unknown even now as the practical consequences of the laser were in the 1960s. The first uses have been to make better measurements of physical constants.

1996

► Anthropology

William H. Kimball and coworkers find in Ethiopia a 2.33-million-year old jaw that they identify as either *Homo habilis* or *Homo rudolfensis*, making it the earliest known specimen of the genus *Homo*. See also 1960 ANTH; 2003 ANTH.

★ Astronomy

Firm evidence is collected that indicates a massive black hole exists at the center of the Milky Way Galaxy. See also 1991 AST; 2000 AST.

Astronomers, using the X-ray satellite *ROSAT*, discover strong X-ray radiation from the comet Hyakutake. The comet, with an unusually long tail, is easily visible with the naked eye. See also 1990 AST; 1997 AST.

Andrea Dupree [b. 1939] and Ronald Gilliland [b. 1939] photograph the stellar disk of Betelgeuse with the *Hubble Space Telescope*. This is the first image other than a point of a star except for the Sun. See also 1920 AST.

A team of the European Southern Observatory discovers with the Swedish Submillimeter Telescope on the La Silla Mountain in Chile the first extragalactic silicon-monoxide laser. It is the largest known star, IRAS 04553–6825, a red supergiant in the Large Magellanic Cloud. Because of its size, it loses material to space, which causes it to radiate strongly at the 3 mm wavelength.

Astronomers from the United Kingdom, Canada, and Australia conclude upon studying Hubble deep field images that the galaxies that existed when the universe was about 30 per-

cent of its present age have very different shapes from the galaxies that are younger and therefore cannot be classified by the Hubble classification system of galaxies. See also 1925 AST.

A two-year-long analysis of data from the *Clementine* space probe reveals that the Moon may have water ice mixed with dust at the surface of the lunar south pole, where there is a deep shadowed basin. See also 1994 AST; 1998 AST.

Scientists who have analyzed a meteorite thought to have originated on the surface of Mars believe that it shows evidence of life having once existed in the form of bacteria on that planet. This claim will be disputed and reaffirmed several times in the next few years.

A large asteroid, comet, or planetoid, known as 1996TL66, is observed in an orbit that carries it three times as far from the Sun as Pluto and then back to the farther reaches of Pluto's orbit. The surface area of the 500-km (300-mi) object is about the size of Texas.

On February 17 the space probe *Near Earth Asteroid Rendezvous* (later renamed *Shoemaker Near Earth Asteroid Rendezvous* after Eugene Shoemaker [b. Los Angeles, April 28, 1928, d. Alice Springs, Australia, July 18, 1997] — abbreviated *NEAR Shoemaker*) is launched by the United States. Its main goal is a rendezvous with the asteroid 433 Eros. See also 2000 AST.

On April 30 the small orbiting observatory *BeppoSAX* (*Satellite per Astronomica a Raggi X*) is launched by the European Space Agency in conjunction with Italy and the Netherlands. It studies X-ray emit-

ting events from outer space. See also 1997 AST.

On November 7 the United States launches the space probe *Mars Global Surveyor*, intended to orbit Mars for one Mars year, or 687 days. See also 1999 AST.

On December 4 the United States launches the space probe *Mars Pathfinder*, intended to soft-land on Mars and study the geology of the planet. See also 1997 AST.

At the W.M. Keck Observatory on Mauna Kea, Hawaii, the Keck II telescope joins its twin, Keck I. See also 1993 AST.

In the Kamioka Mine, Japan, the Super-Kamiokande neutrino telescope begins operation. It consists of a tank 40 m (130 ft) in diameter and 40 m (130 ft) tall filled with 50,000 tons of ultrapure water. The device observes Cerenkov radiation (flashes of light caused when a muon moves faster than the speed that light moves in water) with about 13,000 photomultiplier tubes on the walls of the tank. See also 1987 AST; 2001 AST.

The Antarctic Muon and Neutrino Detector Array (AMANDA), which is designed to detect neutrinos with photomultipliers buried in the ice at the South Pole, undergoes the first tests to determine if the concept is workable. See also 2000 AST.

✿ Biology

Gavin R. Hunt reports that the crow *Corvus monedulaoides* of the New Caledonia islands makes and uses several different kinds of specialized tools with which it searches for and captures hidden insects. Typical tools include hooks to snare food that is out of reach.

The tools are made from whatever material is at hand. See also 1960 ANTH.

The yeast genome sequence is completed by an international consortium, the first sequencing of a gene from a eukaryote (an organism other than bacteria or archaeans). See also 1995 BIO; 1999 BIO.

The genome for RSV (respiratory syncytial virus), a severe lung disease of infants, is sequenced. See also 1995 BIO; 1997 BIO.

▷ Chemistry

Scientists at the Society for Heavy Ion Research in Darmstadt, Germany, create a few atoms of element 112.

Robert F. Curl, Jr. [b. Alice, Texas, August 23, 1933], Richard Smalley, and Harold Kroto are awarded the Nobel Prize in chemistry for their discovery of fullerenes, notably buckminsterfullerene, giant carbon molecules that enclose empty spaces (buckminsterfullerene has 60 carbon atoms arranged in pentagons, resembling a soccer ball; it is named for its use of the structure of the geodesic dome invented by Buckminster Fuller). See also 1985 CHEM.

▀ Computers

David Corey and colleagues show how nuclear magnetic resonance (NMR) theoretically can be used for building small quantum computers. See also 1994 MATH; 2001 MATH.

⊕ Earth science

A dinosaur covered with downlike feathers is discovered in the Liaoning Province of northeastern China and named *Sinosauropelta prima*. Another dinosaur fossil, *Unenlagia comahuensis*, in

body structure the most bird-like dinosaur to date, is found in southern Argentina. *See also* 1998 EAR.

Scientists from the Scripps Institution of Oceanography at San Diego find evidence that life on Earth existed as early as 3,850,000,000 years BP.

On February 24 the United States launches the satellite *Polar* to report on the interaction of the solar wind with Earth's magnetic field. *Polar*, as its name implies, concentrates on the region near Earth's magnetic poles, taking ultraviolet images of Earth's auroras and X-ray images of high-speed electrons sparked by the solar wind.

On August 21 the United States launches the small satellite *FAST* (*Fast Auroral Snapshot*) to study the auroras from low-Earth orbit.

❖ Ecology & the environment

The U.S. National Oceanic and Atmospheric Administration (NOAA) reports measurements that demonstrate that international treaties to lower the production of chemicals that damage the ozone layer of the atmosphere are working. NOAA expects that actual recovery of the layer will begin about 2020 and that the Antarctic ozone "hole" will have closed by 2050. *See also* 1990 ECOL.

♥ Medicine & health

A new variant of Creutzfeldt-Jacob disease is discovered in the United Kingdom. The disease is transmitted to humans via the meat of cattle infected with bovine spongiform encephalopathy (a.k.a. mad cow disease).

Peter C. Doherty [b. Australia, October 15, 1940] and Rolf M. Zinkernagel [b. Basel, Switzerland, January 6, 1944] are awarded the Nobel Prize in physiology or medicine for explaining how the human body's immune system identifies cells infected with viruses.

❖ Physics

Sipko L. Boersma shows that a force equivalent to the Casimir effect is the cause of a phenomenon long noted by sailors — ships parallel to each other floating side by side are pulled together (sometimes with disastrous consequences). Wave action between the ships is reduced by the constricted area, but on the side to the open sea, waves continue to push on the hulls, forcing the two ships toward each other. *See also* 1948 PHY.

Robert C. Richardson [b. Washington, DC, June 26, 1937], David M. Lee [b. Rye, New York, January 20, 1931], and Douglas S. Osheroff [b. Aberdeen, Washington, 1945] are awarded the Nobel Prize in physics for their discovery of superfluidity in helium-3, which is a different form of superfluidity from that in the more common form of helium, helium-4. A superfluid is able to maintain vortexes without loss of energy and can flow without friction.

I Tools

Roetta Inpharmatics makes the commercial introduction of DNA microarrays — also known as DNA chips — which use thousands of DNA strands attached to a silicon chip to detect specific molecules, which then show up as colored dots when examined with a scanner.

1997

◀ Anthropology

By comparing the DNA from Neandertal remains to the DNA of modern humans, Svante Pääbo of the University of Munich and coworkers conclude that the Neandertal was a different species from *Homo sapiens*. *See also* 1999 ANTH.

David DeGusta, Cesur Pehlevan, and Berhane Asfaw, part of a team led by Tim White, find the oldest modern humans known, three skulls from Herto in the Middle Awash region of Ethiopia. The skulls are in fragments and require considerable reconstruction before they can be identified. *See also* 2003 ANTH.

A re-examination of fossils from Java suggest that *Homo erectus* may have existed on that island as recently as 27,000 to 53,000 years BP, which would make *H. erectus* contemporary with *H. sapiens* in that species' early years, since fully modern humans are known from as early as 90,000 years BP. *See also* 1895 ANTH.

▀ Archaeology

Thomas Dillehay presents detailed information that Monte Verde in Chile was occupied by humans at least 12,500 years BP, a date difficult to reconcile with the accepted entrance of humans to the New World from the northern part of North America about 11,500 BP. *See also* 1988 ARCH; 2000 ARCH.

William J. Conklin of the Textile Museum in Washington, DC, proposes the Inca quipu (a.k.a. khipu) records infor-

mation in a binary code that includes the material (wool or cotton), the slant of the string, the direction of a knot, and so forth, giving as many as $2^6 \times 24$, or 1536, bits of information for each knotted string. A quipu, long known to record numerical data in its dozens of knotted strings, might also with this system record words, just as a modern computer uses a binary code as the basis of word processing. *See also* 1923 ARCH; 2003 ARCH.

★ Astronomy

Astronomers observe with the *BeppoSAX* satellite that a gamma-ray burst on February 28 is followed by a radiation afterglow lasting several days. *See also* 1996 AST; 2003 AST.

NASA's *Mars Pathfinder* space probe lands on Mars in the Area Vallis region, arriving on July 4, releasing an automated six-wheeled, solar-powered "rover" named *Sojourner*, which travels the surface during the day, reporting on Martian geology. *Sojourner* is 28 cm (11 in.) high and 63 cm (25 in.) long. *See also* 1996 AST.

Jupiter's moon Europa is found to be covered by liquid water under a thick outer layer of ice. Astronomers propose that Europa may harbor living organisms in the water flowing under the ice.

Comet Hale-Bopp, an extremely large comet first observed by amateur astronomers on July 22, 1995, makes its closest approach to Earth. At this time, it is visible with the naked eye. Scientists detect a host of organic compounds in its tail. *See also* 1996 AST.



SOJOURNER EXPLORES THE GEOLOGY OF MARS *Sojourner* was a six-wheeled robot powered with its own photoelectric array and batteries. It used a device called the Alpha Proton X-Ray Spectrometer to determine the composition of rocks near the landing site of *Mars Pathfinder*, which relayed the findings to scientists on Earth. The scientists were able to observe the region around the landing site with *Pathfinder's* cameras and direct *Sojourner* to sites they wished to examine.

Astronomers from the University of Cambridge, England, discover the Antlia Galaxy, a small member of the 30-some galaxies that constitute the Local Group (which includes the Milky Way and Andromeda galaxies).

A study of data from the *Compton Gamma Ray Observatory* in space reveals jets of positrons (antielectrons) emanating from the center of the Milky Way Galaxy. They interact with ordinary electrons to produce radiation with a characteristic wavelength, which, expressed as energy, is 0.511 MeV, exactly the energy-mass of an electron. *See also* 1991 AST.

On June 30, as the space probe *NEAR Shoemaker* travels toward its destination at asteroid 243 Ida, it passes by and images asteroid 253 Mathilde, a 66 by 48 km (41 by 30 mi) low-density object covered

with several very large craters. *See also* 1996 AST.

On February 12 Japan launches the radio telescope satellite *HALKA*, which is renamed *VSOP*. This will add a space-based component to radio telescopes on Earth, enabling finer-resolution interferometry. The combination with Earth-based radio telescopes and *VSOP* is termed the Very Long Baseline Space Observatory. *See also* 1993 AST.

On August 25 the United States launches the *Advanced Composition Explorer (ACE)* satellite, which will study the solar wind and cosmic rays from a stable point where the gravity from Earth and Sun are in balance.

On October 15 the United States in conjunction with the European Space Agency launches the *Cassini-Huygens* mission, in many ways the most advanced space probe to date. Its goal is the study of Saturn and its satellites, with the *Cassini* orbiter to travel around the planet as the *Huygens* lander plunges into Saturn's atmosphere for a closer look. Along the way *Cassini-Huygens* will get a gravity boost from Jupiter, giving it a chance to report on that planet as it flies by.

☒ **Biology**

Ian Wilmut and a team at the Roslin Institute in Roslin, Scotland, clone the first mammal using a differentiated cell taken from an adult. The result is a sheep named Dolly born on February 23, the clone of an adult ewe. Dolly is the one success from an experiment that began with the creation of 277 egg cells that contained the nuclear material from

breast cells of a six-year-old ewe. Some 28 of these cells that began to develop into embryos had been implanted in surrogate ewes, but Dolly was the only one to undergo normal development. *See also* 1984 BIO; 1998 BIO.

The *Escherichia coli* genome is sequenced. *See also* 1995 BIO; 1999 BIO.

A team at the Case Western Reserve School of Medicine creates the first artificial human chromosome. *See also* 1983 BIO.

Paul D. Boyer [b. Provo, Utah, July 31, 1918], John E. Walker [b. Halifax, Yorkshire, England, January 7, 1941], and Jens C. Skou [b. Lemvig, Denmark, October 8, 1918] are awarded the Nobel Prize in chemistry. Boyer and Walker are given the prize for studies in how organisms produce ATP (adenosine triphosphate), the ubiquitous molecule used as the immediate energy source by cells. Skou discovered how ATP is used in maintaining the balance of sodium and potassium, major chemical messengers in cells.

▷ **Chemistry**

Peter Armbruster and his team at GSI in Darmstadt, Germany, produce a single atom of atomic mass of 277 and atomic number 112 by smashing zinc atoms into a lead target.

⌚ **Communication**

TiVo, Inc. is founded to introduce the digital video recorder into people's homes. Essentially the same as a large-capacity hard drive, the TiVo system not only records television programs, but because of a constantly running buffer, is

capable of pausing a program and resuming it later without missing any part and also of reshowing a small segment of a show being watched when asked, even though that show was not being recorded at the time. TiVo also includes a feature that determines which shows a viewer records and then records similar shows without being told to do so (this feature can be turned off, however, by the viewer). Soon a competitive system, called Instant Replay, that uses similar technology, will be introduced.

💻 **Computers**

Deep Blue, an IBM RS/6000 SP computer, defeats the world chess champion Gary Kasparov in a six-game match, the first time a computer defeats a human player of this caliber. *See also* 1989 COMP.

Intel's Janus supercomputer, installed at the Sandia National Laboratories in Albuquerque, New Mexico, sets a new record as the first teraflop computer; this means that it performs trillions of operations per second. *See also* 2002 COMP.

🌐 **Earth science**

A team of oceanographers identifies the only known deep-sea impact of a large (1 to 4 km diameter) object, the Eltanin impact in deep waters off the coast of Antarctica near South America some 2,150,000 years ago. *See also* 1991 EAR.

On November 27 the Earth-observing satellite *TRMM (Tropical Rainfall Measuring Mission)* is launched by the United States in concert with Japan. It will use microwave radar, visible light, and

Time shifting

One of the unexpected changes of the Information Age has been time shifting. This takes two main forms. One of them is that it is no longer necessary for an individual to plan a specific time for an event. Instead, the event occurs when the person is ready for it. The other form is that events for which there had in the past been a lag, during which something else could happen, now take place instantaneously.

The second form of time shifting, the loss of lag, is less a new development than it is the final (or near final) culmination of a trend that goes back to the domestication of horses (which enabled transfer of information faster than humans can travel) and that has continued at an exponentially accelerating pace since. The steps from exchange of information over a period of months to a period of days to one of hours to instantly have come faster than we have had time to think about in recent years. In the 1980s business changed suddenly from use of mail services that took days or even weeks to the use of overnight mail. In the 1990s, everything shifted further into the present through faxes and e-mail (mostly traveling on telephone lines), and increased use of the older instantaneous system, the telephone for voice communication. After 2000 the pager and the cell phone made the telephone even more a part of life, as people walked or drove while conversing with someone who might be doing the same. Even e-mail seemed too slow at times; instant messaging was invented and like the cell phone, it became part of a new way of life. No wonder people came to depend on personal data assistants (PDAs) to keep track of their time.

During the same quarter century, data storage permitted time shifting of the first type to occur — moving an event from its original time to a more convenient one. Although faxes transmit almost instantaneously, they also can be sent to a machine in the dead of night to be read whenever the receiver feels like it. Electronic mail is likewise both instantaneous and shiftable. Unlike old-fashioned voice communication over a telephone, there is never a busy signal or nobody home with electronic mail; the message is delivered instantly, but can be picked up at the receiver's convenience. Even today's business telephones encourage time shifting by using powerful answering machines called voice mail.

The advent of moderately easy to use video recording in the 1980s and 1990s allowed families to time shift their entertainment. If they want to watch a program scheduled for an inconvenient time, they can tape it for replay later. Even the technologically challenged did not have to schedule a trip to a motion-picture theater; they could pick up a video or DVD and watch it when they were ready. The use of digital video recorders (DVRs), such as TiVo and Instant Replay, encouraged this even more, making it easy to schedule recordings of programs far in advance and to skip commercials when viewing them. Cable television, in response, began to develop its own systems for viewing programs whenever the customer wanted, not when the company decided to show them. Similarly, people found ways to create their own music collections by downloading songs and ways to listen to the music using a variety of extremely portable players.

Similarly, bankers' hours no longer matter to the customer, who can deposit checks, pay bills, transfer money, or obtain cash at any time of the day or night from automated teller machines (ATMs). With the Internet, it also became possible to schedule electronic payments for checks far in advance; when the date arrives, the bank makes the payment.

One factor that makes time shifting possible has been the acceptance of standards. Facsimile transmission is an old technology that was introduced about the same time as radio and motion pictures, but for a long time it was used only by newspapers or other specialists in transmitting photographs. In the 1970s and 1980s international standards were set for fax transmission, which, along with the less expensive devices made possible by microprocessors, ensured that a person with no special training or experience could successfully send or receive a fax on the first try. This should be contrasted with the introduction of the use of the modem for communication directly between computers. There were so many different standards available that it often took a day or two to get two computers to agree on a set of protocols before the modems could be used. Sometimes necessary standards are set by official bodies, as with the fax, and other times they are set by the public, who, for example, chose the VHS standard for videotape over several other incompatible systems. In the case of modems, the Internet replaced the need for matching standards from one computer to another.

infrared radiation to investigate how El Niño is affecting rainfall in the tropics and subtropics. *See also* 1982 EAR.

The German satellite *Equator-S* orbits Earth's equatorial plane after a December 2 launch. It studies Earth's magnetic field.

❖ Ecology & the environment

In Kyoto, Japan, representatives from more than 150 countries on December 11 accept the Kyoto Protocol, an agreement to reduce emissions of greenhouse gases, subject to ratification by their

governments. They agree to reduce emissions of greenhouse gases by a total of 5.2 percent worldwide by 2010. By 2003 some 106 states will have ratified it (but not the United States, Russia, or Australia). *See also* 1995 ECOL; 2001 ECOL.

❖ Electronics

IBM engineers develop a way to use copper to connect parts of silicon computer chips, an advance that speeds chip operations.

❖ Medicine & health

Ian Wilmut and his team at

the Roslin Institute in Roslin, Scotland, clone a sheep, named Polly (not to be confused with Dolly), from a fetal cell that has had the gene for human blood clotting factor IX inserted into it, aiming to extract the factor from the adult sheep. *See also* 1997 BIO.

Stanley Prusiner is awarded the Nobel Prize in physiology or medicine for discovering proteins called prions, which appear to cause certain infectious brain diseases, such as bovine spongiform encephalopathy ("mad cow disease"). *See also* 1982 MED.

* Physics

Wolfgang Ketterle demonstrates interference fringes in two overlapping Bose-Einstein condensates expanding from a trap; the matter waves are coherent and therefore the device producing these atom beams is called an atom laser. *See also* 1995 PHY.

Two groups of physicists, one in Austria and one in Rome, demonstrate teleported photons for the first time, although the photons are destroyed in the measurement process. This is accomplished through the entanglement of two particles so that measuring the exact quantum state on one instantly determines the state of the other no matter where it may be in the universe. The process is named quantum teleportation. *See also* 1982 PHY.

Steven Chu, Claude Cohen-Tannoudji [b. Constantine, Algeria, 1933], and William D. Phillips [b. Wilkes-Barre, Pennsylvania, November 5, 1948] are awarded the Nobel Prize in physics for their development of methods to trap and observe individual atoms. *See also* 1985 PHY.

→ Transportation

On April 3 the Yamanashi Maglev Test Line opens in

Japan. Trains soon exceed speeds of 500 km (300 mi) per hour in test runs along 42.8 km (26.5 mi) of track. *See also* 1990 TRAN; 2003 TRAN.

1998

★ Astronomy

Two groups, one headed by Saul Perlmutter of Lawrence Berkeley National Laboratory in California and the other led by Brian Schmidt of the Mount Stromlo Observatory near Canberra, Australia, discover by observing distant Type I supernovae that the universe's expansion is speeding up. This conclusion comes from comparing the distance to the supernovae revealed by two different measures, redshift and brightness. Because redshift distances are based on how fast the universe is expanding, when the brightness measurements (independent of expansion) reveal far-

ther distances than redshifts do, the implication is that the universe expands more quickly at greater distances. The astronomers postulate that some force is accelerating expansion, which before this had been expected to slow down. The still unknown force is called dark energy.

Data from satellite-borne X-ray telescopes combined with optical data from the Keck II telescope reveal the largest known explosion since the big bang — a burst of gamma rays as luminous for a second or two as the rest of the universe. The cause of the explosion remains unknown.

A burst of X rays from the object SGR 1900+14 reveals that the object is the first known magnetar (predicted by theorists since 1992), a type of neutron star that produces the most intense magnetic fields known in the universe.

Dark energy

After discovering that most of the matter in the universe is invisible, astronomers also found that most of the energy in the universe is hidden as well. This hidden energy causes the expansion rate of the universe to increase. Two groups discovered in 1998 that supernovae in very distant galaxies are farther away than if the expansion of the universe was caused by the big bang alone.

Type 1 supernovae, sometimes observed in distant galaxies, are excellent distance indicators because they all reach the same brightness during the explosion, and from their apparent luminosity one can deduce their distance directly. Many of these supernovae are dimmer than expected from their redshifts alone, indicating that they are much farther away and that there is a force driving distant galaxies apart.

Albert Einstein introduced such a force, termed the cosmological constant, when he developed his theory of relativity. He believed the universe to be static, and the cosmological constant

would prevent the gravitational collapse of the universe because of gravitational forces. Later, when it became known that the universe is expanding, the cosmological constant became known as Einstein's blunder.

In 2002 a third group of astronomers found that a number of galaxies observed through gravitational lenses are so far away that the galaxies cannot have been carried that distance by the expansion of the universe alone. Gravitational lenses produce multiple images of galaxies behind them. The rays travel over slightly different distances if they are deflected at the rim of a gravitational lens or if they pass straight through the middle of the lens; from differences in arrival time astronomers can determine directly how far away these objects are. Also, the magnification produced by the lens allows very distant objects behind it to be seen.

The nature of the dark force is still unknown. Some argue that it is a force associated with the vacuum and call it quintessence, meaning that it is a fifth force in addition to the known four fundamental forces (gravity, electromagnetism, the weak interaction and the strong force).

Astronomers use images produced by the *Galileo* space probe during its orbits about Jupiter to determine that the giant planet has four separate rings instead of only one. Each ring is produced by the passage of a shepherding moon. The shepherds are Metis, Adrastea, Amalthea, and Thebe, all among the smaller satellites of Jupiter. *See also* 1995 AST.

Raymond Davis publishes the final results of the detection of neutrinos from the Sun with the detector at the Homestake Gold Mine in South Dakota, and concludes that fewer neutrinos have been detected than predicted by current theories. *See* 1965 AST; 2002 AST.

In Cerro Paranal, Chile, the first mirror of the Very Large Telescope (VLT), operated by the European Southern Observatory (which includes Belgium, Denmark, France, Germany, Italy, the Netherlands, Sweden, and Switzerland), sees its "first light" on May 25. When completed, the VLT will combine four mirrors, each 8.2 m (323 in.) in diameter. *See also* 2000 AST.

The *Voyager 1* space probe becomes the most distant artificial object, reaching some 10,400,000,000 km (6,500,000,000 mi) from Earth on February 17. By 2003 *Voyager 1* will reach a distance of about 13,500,000,000 km (8,400,000,000 mi) and continue on its way.

On January 6 the United States launches the *Lunar Prospector*, a space probe that orbits the Moon. It confirms the discovery made earlier by the probe *Clementine* that there is water in deep craters at the Moon's poles. *See also* 1996 AST.

On April 2 the United States launches *TRACE* (*Transition Regions and Coronal Explorer*), an Earth-orbiting satellite that will use its ultraviolet telescope to study magnetism in the Sun's corona.

On July 4 Japan launches *Nozomi* ("hope"), a.k.a. *Planet B*, which is originally planned for an orbit about Mars beginning in October 1999, from which it will study the Martian atmosphere and its interaction with the solar wind. Problems will develop and to conserve fuel the planned orbit about Mars is put off until 2004.

On December 5 the United States launches *SWAS* (*Submillimeter Wave Astronomy Satellite*), a space-based radio telescope that will study the chemical composition of interstellar gas clouds, the homes of new stars.

In the Gran Sasso Tunnel, Italy, astronomers from Italy and Germany begin operations of the Gallium Neutrino Observatory, using 100 tons of gallium chloride. As in the earlier GALLEX experiment, they study solar neutrinos observed when the neutrinos strike gallium atoms and transmute them to germanium. *See also* 1991 AST.

Biology

Scientists at the University of Wisconsin grow human embryonic stem cells in tissue culture. The embryonic stem cells are those that differentiate to form all the tissues and organs as the embryo grows into a person. *See also* 1961 MED; 2001 MED.

Dolly, the first mammal cloned from a differentiated

Neutrino mass

One of the most enigmatic members of the particle zoo is the neutrino. Predicted by Wolfgang Pauli in 1930, it was only detected in 1956, when Fredrick Reines and Clyde Cowan captured neutrinos that had been produced in a nuclear reactor. Neutrinos are extremely difficult to detect because they hardly interact with matter at all — only one in a million of the neutrinos traversing Earth collide with an atomic nucleus.

In 1967 Raymond Davis, using a huge tank of cleaning fluid (HCl_4) placed deep underground to shield it from cosmic rays, started looking for neutrinos produced by the nuclear reactions in the Sun's core, but he could only detect about half of what was expected. Other underground detectors found similar neutrino shortages.

As early as 1957 the Italian physicist Bruno Pontecorvo had proposed that neutrinos might change from one type or "flavor" into another, a phenomenon called oscillation. Gradually, physicists started to suspect that oscillation could explain the shortfall of neutrinos detected from the Sun. The detectors could capture only one type of neutrino, and neutrinos during their journey from the Sun changed flavor and escaped detection.

According to the "standard model," the theory describing all the elementary particles and their interactions, neutrinos should have zero mass. However, quantum theory requires that if neutrinos change flavor they must have mass. Several experiments with atmospheric neutrinos and so-called long-baseline experiments in which neutrinos are beamed from a source to a distant detector have confirmed that neutrinos change flavor and so have mass.

Because neutrinos are very abundant in the universe, they would account for a sizable portion of the missing mass in the universe — but not all of the missing mass — and they could not, because of their great speed, account for the formation of galaxies. Gravitational clumping in the early universe may require yet another almost undetectable particle.

adult somatic cell, delivers a lamb, conceived and produced by the time-honored natural method. *See also* 1997 BIO.

Roderick MacKinnon and coworker determine the three-dimensional shape of a specific large protein molecule that acts as the gate allowing potassium ions to enter or leave cells. Pas-

sage of ions, especially those of sodium and potassium, creates the voltage pulses that are messages between nerve cells and that also are involved in all forms of cell communication. *See also* 2002 BIO.

Chemistry

Scientists at the Berkeley and Lawrence Livermore Labora-

tories in California and, independently, at the Dubna Institute in Russia create element 114.

Walter Kohn [b. Vienna, Austria, 1923] and John A. Pople [b. Burnham-on-Sea, England, October 31, 1925] are awarded the Nobel Prize in chemistry for the use of quantum mechanics in predicting chemical reactions, enabling them to design molecules for specific applications.

■ Construction

A new record for the length of a suspended main span for a bridge is set at 9907 m (32,503 ft) by the Akashi Kaikyo Bridge near Kobe, Japan. *See also* 1986 CONS.

● Earth science

South African scientists find evidence that life on land has existed for more than 2,000,000,000 years. Earlier estimates were that the first land-dwelling animals emerged from the sea about 475,000,000 years BP. *See also* 1996 EAR.

Jess F. Adkins of Lamont-Doherty Earth Observatory and coworkers establish that deep currents in the ocean change much more rapidly than previously thought, which may contribute to sudden changes in global climate.

Ji Quong, Ji Shu An, and Mark A. Norell [b. St. Paul, Minnesota, July 26, 1957] announce the discovery of two species of dinosaur with true feathers that have been found in the Liaoning, China, fossil bed. *See also* 1996 EAR; 2001 EAR.

On December 4 Argentina

launches SAC-A, a satellite with many duties, including digital global positioning, studies of Earth's magnetosphere, and whale tracking.

■ Electronics

Researchers at Denmark's national microelectronics center (MIC) demonstrate that they can, by using a scanning tunneling microscope, switch a single hydrogen atom back and forth between two silicon atoms just a quarter nanometer apart. This can be accomplished at room temperature, but a high vacuum is required. The feat is considered a step toward developing a computer chip that operates on a single-atom basis. *See also* 1991 ELEC.

▼ Energy

John A. Turner and Oscar Khaselev of the U. S. National Renewable Energy Laboratory in Golden, Colorado, develop a solar cell that can split water into hydrogen and oxygen. *See also* 1989 ENER.

Σ Mathematics

John Friedlander of the University of Toronto and Henryk Iwaniec of Rutgers University show that there are an infinite number of the sums of two fourth powers that are also prime numbers (for example, $1^4 + 2^4 = 1 + 16 = 17$, which is prime and $2^4 + 3^4 = 16 + 81 = 97$, which is also prime; but not all sums of two fourth powers are prime, since $1^4 + 3^4 = 1 + 81$, which is not prime).

Thomas C. Hales [b. 1958] produces a computer-aided proof that the conjecture formulated by Johannes Kepler in 1611, stating that the face-centered cubic configuration

of spheres, whereby each sphere rests in the hollow formed by three adjacent spheres, is the densest way to pack spheres. *See also* 1999 MATH.

All possible knots with 16 or fewer crossings are cataloged — a total of 1,701,936 different knots — independently by two different groups of mathematicians. These are mathematical knots, which, unlike Boy Scout or sailor's knots, are tied and then have the ends of the rope joined so that they cannot be untied. Increasingly, the theory of knots has become an important part of algebra, while there are also suggestions that knot theory may have significance for particle physics and for biology.

♥ Medicine & health

Elizabeth Gould and coworkers at Princeton University demonstrate that adult monkeys continue to grow new brain cells, a feat previously believed to be impossible for primates. Later research will confirm that the same growth takes place in adult human brains.

Pfizer introduces Viagra, the first oral medication effective against male erectile dysfunction (impotence). *See also* 1995 MED.

Robert F. Furchtgott [b. Charleston, South Carolina, June 4, 1916], Louis J. Ignarro [b. Brooklyn, New York, May 31, 1941], and Ferid Murad [b. Whiting, Indiana, September 14, 1936] are awarded the Nobel Prize in physiology or medicine for discovering that the gas nitric oxide is an essential signaling molecule in the cardiovascular system.

⊗ Physics

Researchers in Japan, using the Super-Kamiokande neutrino detector, report evidence of neutrino oscillation, an indication that the tiny subatomic particles possess mass after all (the standard model of particle physics assumes that neutrinos have zero mass). *See also* 1957 PHY; 2000 PHY.

Physicists at the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, observe the last of the 15 mesons predicted by the standard model of particle physics. *See also* 1935 PHY.

Another Fermilab team and independently a team from CERN demonstrate that some particle reactions are not time invariant; that is, they would not reverse exactly if time were to flow backwards. This result had been implied by earlier research on CPT (charge-conjugation, parity, time) invariance, but had not been demonstrated for time reversal by itself. *See also* 1964 PHY.

Using the method of least squares, CODATA (the Committee on Data for Science and Technology) readjusts the value of some 300 fundamental physical constants, reducing uncertainties to 20 percent or less of what they had been previously (except for the gravitational constant, which was found to be even more uncertain than previously determined). *See also* 1966 PHY.

Robert B. Laughlin [b. Visalia, California, November 1, 1950], Horst L. Störmer [b. Frankfurt am Main, Germany, April 6, 1949], and Daniel C. Tsui [b. Henan Province, China, 1939]

are awarded the Nobel Prize in physics for their discovery of the fractional quantum Hall effect, an unusual macroscopic manifestation of quantum mechanics in which ratios of electric potential are found only as specific rational fractions such as $1/3$, $2/3$, $2/5$, and $1/7$, suggesting that free electrons are behaving somewhat as a liquid instead of as particles forming a kind of "gas" in a semiconductor.

→ Transportation

On October 24 the United States launches *Deep Space 1* to test new technologies, including an ion-propulsion system.

Construction of the *International Space Station* (ISS) is started by a consortium of 16 nations in November when Russia launches the first module, called the Zarya utility module. In December the United States adds a docking module called Unity that will permit space shuttles and Salyut rockets to deliver parts and crew. *See also 2000 TRAN.*



THE INTERNATIONAL SPACE STATION

Streamlining is not necessary in space, where there is no atmospheric resistance, so the modules that form the *International Space Station*, built by different nations and assembled in space, appear somewhat like a Lego sculpture built by a two-year old. In reality, the modules are extremely functional and attached according to the needs of the station and its inhabitants.

1999

◀ Anthropology

Scientists discover a 24,500-year-old skeleton in Portugal that many believe to be a hybrid between a Neandertal and *Homo sapiens*. *See also 1997 ANTH.*

Berhane Asfaw and coworkers announce the discovery of fossils of a new hominid species in Ethiopia, which they name *Australopithecus garhi* ("surprising australopithecine"); it dates from 2,500,000 years BP. Evidence of animal butchering with stone tools is found in the same stratum, although no absolute connection can be made between the australopithecine and the butchering.

▲ Archaeology

Zahi Hawass [b. Damietta, Egypt, May 28, 1947] and other Egyptian archaeologists discover at Bahariya Oasis, some 140 km (230 mi) from Cairo, a previously unknown cemetery that contains an estimated 10,000 mummies. They name the site the Valley of the Golden Mummies, since the first mummies found have gold face masks and gold-covered vests. *See also 1984 ARCH.*

★ Astronomy

Geoffrey W. Marcy of San Francisco State University and Robert Noyes of the Harvard-Smithsonian Center for Astrophysics discover that there are at least three planets orbiting the star Upsilon Andromedae, a star about 44 light-years from Earth. Two planets are much larger than Jupiter, while the third, about $3/4$ the size of Jupiter, is orbiting the star so closely that its period is

Geoffrey W. Marcy

[b. Detroit, Michigan, September 29, 1954]

At a time when most astronomers thought extrasolar planets would be impossible to observe, Marcy decided to search anyway. He was able to use a recently upgraded spectrograph at Lick Observatory that could detect very small variations in the frequency of starlight. With this tool, a small wobble in a star's position could be discerned from the frequency variation it caused. A regular wobble almost certainly would be caused by the gravitational pull of a planet orbiting the star. In 1987 Marcy and coworker Paul Butler of the Carnegie Institution of Washington used the spectrograph to discover the second and third extrasolar planets known. Since then Marcy and Butler have discovered about two-thirds of all known extrasolar planets, including systems of several extrasolar planets around Sun-like stars.

only 4.6 Earth days; thus, this first nonsolar system of planets to be discovered is not much like our familiar solar system. *See also 1995 AST.*

Gregory W. Henry becomes the first astronomer to observe the periodic dimming of light from star HD 209458; this is caused by an extrasolar planet orbiting the star. *See also 1995 AST.*

The Sloan Digital Sky Survey begins. It uses the largest electronic camera ever built to map millions of galaxies and other objects visible from our galaxy.

Philip Lucas and Patrick Roche discover 13 free-floating extrasolar "planets" in the Orion Nebula. Since these small bodies are not in orbit about a star, however, they will later be termed "planetars" or "sub-brown dwarfs." They are not brown dwarfs because they have masses below 13 times that of Jupiter. At a mass of 13 Jupiters, bodies produce limited nuclear reactions, making brown dwarfs low-level cousins of stars. *See also 1987 AST.*

On January 23 the Robotic Optical Transient Search Experiment (ROTSE) near Los Alamos National Labora-

tory in New Mexico observes the first optical image associated with a gamma-ray burst. The light from GRB 990123 is captured just 22 seconds after the explosion is recognized by gamma-ray detecting satellites. GRB 990123 is also the most powerful gamma-ray burst observed to this date. Current theory holds that the gamma-ray bursts occur when a giant star collapses into a black hole, sending out jets that produce the bursts as they strike nearby gas or dust. *See also 2002 AST.*

On February 7 the United States launches the space probe *Stardust*. Its mission is the capture and return to Earth of dust from comet Wild 2, which it is scheduled to reach in January 2004. *Stardust* is expected to parachute the samples back to Earth in 2006.

In March *Mars Global Surveyor* enters its orbit about the planet Mars, beginning a study that will last for at least one Mars year of 687 days. Among its first discoveries is that fossil magnetism, which can be detected from space, indicates that 4,000,000,000 years ago Mars had active tectonic plates, similar to those known on Earth. It also finds

additional evidence that water once flowed over the Martian surface. *See also* 1996 AST.

On June 24 the United States in conjunction with Canada and France launches *FUSE* (*Far Ultraviolet Spectroscopic Explorer*), a space-based telescope that will explore the universe at wavelengths slightly longer than X rays. *FUSE* fills a gap in astronomers' coverage of the electromagnetic spectrum.

On July 23 the United States launches the *Chandra X-Ray Observatory*, a space-based telescope that will become among the most successful of NASA's observatories. *See also* 1995 AST.

On December 10 the European Space Agency launches the *X-Ray Multi-Mirror Telescope*, generally known as *XXM-Newton*. This is the most powerful X-ray detector ever put into space. *XXM-Newton* has three X-ray telescopes, two X-ray spectrometers, and an optical telescope. Its orbit about Earth takes it a third of the way to the Moon, giving it long periods of time for observation of stars, pulsars, active galaxies, and black holes. *See also* 1996 AST.

The Hobby-Eberly telescope, dedicated primarily to spectroscopy, begins operation in October at the McDonald Observatory in the Davis Mountains of Texas. It has the world's largest primary mirror at 11 m (433 in.), but is considered the world's third largest telescope at this time (Keck 1 and 2 are first and second) because only 9.2 m (362 in.) of the surface is available for use at any one time. *See also* 1993 AST.

The Gemini North telescope begins operations on Mauna Kea, Hawaii. Its 8-m (319-in.) mirror is to have an exact twin in the Southern Hemisphere. *See also* 2000 AST.

The Subaru telescope on Mauna Kea, Hawaii, with an 8.3-m (338-in.) reflector, begins operation. It is the largest telescope mirror to this time cast from a single piece of glass.

Biology

On December 1 the sequencing of the first human chromosome, chromosome 22, is completed. Both the United States and United Kingdom announce that the human genome will not be patentable. *See also* 1998 BIO; 2000 BIO.

A joint project of the Sanger Centre, near Cambridge, England, and Washington University in St. Louis announces that they have decoded the genome of the nematode *Caenorhabditis elegans*, making it the first animal whose genome is completely known (and previously the first animal for which the development path of each cell had been determined). *C. elegans* is found to have 19,099 genes spread out among some 97,000,000 base pairs of nucleotides in its DNA. *See also* 1996 BIO; 2000 BIO.

Studies in mice show that a process of cell division called telomere shortening produces the effects of cell aging. Telomeres are structures at the end of chromosomes that protect DNA against breakage or other instabilities during cell division. Scientists also discover that telomeres of mammalian chromosomes

form loops that look like tiny lassos. *See also* 1985 BIO.

Joe Z. Tsien of Princeton University and coworkers show that enhancing a component of a mouse brain with genetic engineering can produce a mouse that is more intelligent than one that has not had its brain cells altered. The enhanced part of the brain cell is a molecule called the NMDA receptor. *See also* 1996 BIO.

Heidi Schulz discovers in ooze off the coast of Namibia the largest bacterium known. *Thiomargarita manitobensis* is about the size of the period at the end of this sentence.

German-American Günter Blobel [b. Waltersdorf, Germany, May 21, 1936] is awarded the Nobel Prize in physiology or medicine for determining that proteins carry signals that direct their transport to specific places within a cell.

Chemistry

Scientists at the Joint Institute for Nuclear Research in Dubna create element 114 by smashing calcium atoms into a plutonium target.

Scientists at Lawrence Berkeley National Laboratory in California claim to have extended the periodic table with elements 116 and 118, but will later withdraw the claim after the experiment cannot be replicated and evidence of fraud by one member of the team is found.

Using a combination of X-ray and neutron-diffraction techniques, scientists are able to image for the first time the specific shape of electron orbitals in an atom. *See also* 1955 TOOL.

Egyptian-American Ahmed H.

Zewail [b. Damanhur, Egypt, February 26, 1946] is awarded the Nobel Prize in chemistry for developing a technique that uses a laser to observe the movements of atoms within molecules while a chemical reaction takes place.

Communication

Sole responsibility for registration and maintenance of domain names (such as site names ending in .com, .edu, and .net) is removed from Network Solutions, Inc., which has had a monopoly since 1992. Control is assigned to the nonprofit Internet Corporation for Assigned Names and Numbers (ICANN), formed in 1998. It in turn accredits registrars who assign the actual domain names. *See also* 1992 COMM.

Earth science

Ji Qiang of the Chinese Academy of Geological Sciences locates a nearly complete fossil of a rat-sized creature called a triconodont, thought to be the earliest known ancestor of the mammals, dating from 120,000,000 years BP. The triconodont was equipped with forelegs like those of a mammal and hindlegs like those of a reptile.

Two fossils of tiny cartilaginous fish from 530,000,000 years BP found in Chengjiang in southern China are identified as the first known vertebrates.

On February 23 Denmark puts Earth satellite *Ørsted* into orbit, from which it will make a high-precision map of Earth's magnetic field.

Ecology & the environment

Scientists studying the Green-

land ice sheet determine that it has shrunk substantially since 1994, an effect thought to be caused by global warming. *See also* 1997 ECOL; 2001 ECOL.

Researchers find that active colonies of bacteria live in the ice at the bottom of glaciers.

Herpetologists discover that extra legs, missing limbs, and other deformities often found in frogs are caused by parasitic flatworms called trematodes that infect tadpoles.

The American peregrine falcon (*Falco peregrinus anatum*) is removed from the United States Endangered Species List. The falcon population had declined rapidly after the introduction of DDT, starting during World War II, which caused reproductive failure through eggshell thinning, but began recovery after DDT was banned in the early 1970s. Much of the recovery has been due to captive breeding and re-introduction. *See also* 1994 ECOL; 2001 ECOL.

Restoration of the Florida Everglades begins. The primary goal of the \$7.8 billion, 35-year project is to restore the natural flow of water through much of the basin, which had been in decline since 1948, when the U.S. Army Corps of Engineers began draining wetlands, building dams and levees, and otherwise depleting the Everglades.

❖ Materials

Scientists studying carbon nanotubes discover that the giant molecules conduct electricity with almost no resistance, although nanotubes are not conventional superconductors. Nanotubes also are shown to emit light when an electric current is passed through them.

Furthermore, nanotubes sometimes behave as semiconductors and sometimes behave as metals, depending on how the atomic structure of the tube is aligned. Each of these properties is viewed as potentially of great usefulness, although no applications are immediately forthcoming. *See also* 1991 MATR; 2001 ELEC.

Σ Mathematics

Thomas Hales proves the “honeycomb conjecture”: Tiling a plane in regions of equal area in such a way that there is a minimum length for the edges of the regions requires that the regions be regular hexagons. Bees’ combs have long been thought to use hexagonal cells because this minimizes the amount of wax in the walls. Research with bees indicates, however, that the hexagonal shapes are a fortuitous artifact of the method of construction. *See also* 1998 MATH.

A team led by Yasumasa Kanada calculates the value of π to 206,158,430,000 decimal places. *See also* 1987 MATH.

♥ Medicine & health

On April 22 the United States announces that it will not destroy remaining stocks of the smallpox virus as previously planned. All known legal smallpox viruses are in two laboratories in the United

States and Russia, but there is some fear that illegal stocks exist and that they might be used for biological warfare or terrorism. *See also* 1992 BIO.

Surgeons at the Vanderbilt University Medical Center perform the first successful brain surgery on an unborn fetus. *See also* 1984 MED; 2001 MED.

The first New World cases of human West Nile virus infection appear in New York State, where 62 persons become ill and 2 die. Birds throughout the area also become infected and many die from the disease, which is spread to humans by mosquitoes. *See also* 1937 MED.

The U.S. Surgeon General issues the office’s first-ever report on mental health, which notes that almost half of all Americans with severe mental illness fail to seek treatment.

❀ Physics

Deborah Jin and Brian DeMarco create a Fermi gas of atoms by cooling potassium-40 in a magnetic trap to a temperature of 150 micro Kelvin — 0.0015°C (0.0027°F) above absolute zero. *See also* 1995 PHY.

Lene Vestergaard Hau and coworkers at the Rowland Institute for Science in Cambridge, Massachusetts, use a Bose-Einstein condensate

(BEC) to slow the speed of light to 61 km (38 mi) per hour. *See also* 2001 PHY.

Gerardus ‘t Hooft [b. Den Helder, Netherlands, 1946] and Martinus J.G. Veltman [b. Waalwijk, Netherlands, June 27, 1931] are awarded the Nobel Prize in physics for contributions to the standard theory of subatomic-particle physics that show how to make precise calculations of properties.

I Tools

Scientists at the U.S. National Institutes of Standards and Technology (NIST) use a Bose-Einstein condensate (BEC) to create the first directional atom laser. *See also* 1995 PHY.

2000

▀ Archaeology

Tools found at the Cactus Hill site in Virginia are dated from 15,000 years BP. If dating is correct, this discovery undermines the theory that the first humans reached the United States from Alaska and Canada some 11,500 years BP. *See also* 1997 ARCH; 2003 ARCH.

The Confederate submarine *H.L. Hunley*, which in 1864 became the first submarine to sink an enemy vessel, is raised from the ocean off Charleston, South Carolina.

Lene Vestergaard Hau

[b. Vejle, Denmark, November 13, 1959]

Lene Hau was investigating a newly created form of matter, called a Bose-Einstein condensate (BEC) in the late 1990s, passing light through a very cold cloud of sodium atoms that had huddled together to form the BEC. Although light passed through, it slowed greatly. By 1998 Hau realized that light through the BEC was traveling slower than an airplane flies. Later that year she and her team slowed light to 17 m/sec (38 mph), about the speed of a bicycle racer, causing a sensation when the results were published in 1999. By January 2001, Hau’s team had stopped light completely and restarted it a fraction of a second later. (At almost exactly the same time another group, led by Ronald Walsworth of the Harvard Center for Astrophysics, achieved the same feat.)

★ Astronomy

Michael C. Malin [b. 1950] and Kenneth S. Edgett [b. 1965] discover geologic evidence that liquid water has changed the surface of Mars. Gullies appear on steep slopes, apparently formed by water running down the slopes before evaporating into the thin atmosphere. *See also* 2003 AST.

Studies using the *Chandra X-Ray Observatory* reveal that the pervasive X-ray background of the universe is caused by black holes that lurk near the hearts of most galaxies. *See also* 1996 AST.

Results from the BOOMERANG (Balloon Observations of Millimetric Extra-galactic Radiation and Geophysical) experiment study of cosmic background radiation reveal that the universe is flat, not curved. The actual balloon-borne data collection process took place in 1998. *See also* 1979 AST.

The space probe *Shoemaker Near Earth Asteroid Rendezvous* (NEAR Shoemaker) begins orbiting and studying asteroid 433 Eros in February. *See also* 1996 AST; 2001 AST.

The Green Bank telescope, a radio telescope to replace the one that mysteriously collapsed in 1988, begins operation. At 100 m by 110 m (328 by 361 ft), it is the world's largest fully steerable dish radio telescope.

A very bright fireball (with a magnitude of -17, brighter than the full Moon) is observed on April 6. The meteorite, a fragment weighing 1.75 kg (3.86 lb), is recovered near (and named for) the famous German castle



X RAYS FROM BLACK HOLE The *Chandra X-Ray Observatory* has been an important tool in establishing the existence of several different types of black hole.

Although radiation cannot escape from the black hole itself because of the black hole's powerful gravitational field, gases or dust (or stars) that become trapped in the field swirl into the black hole at such great speeds that they emit X rays, which *Chandra* captures in images like this one.

Neuschwanstein on July 14. The original body is thought to have weighed 300 kg (660 lb), of which perhaps 20 kg (44 lb) might have reached Earth in several pieces. *See also* 1959 AST.

On October 9 the *High Energy Transient Explorer (HETE II)* is launched by the United States in conjunction with France, Japan, and Italy. It will observe, report, and help locate gamma-ray bursters while it also surveys X-ray sources across the universe.

The Very Large Telescope (VLT) in Cerro Paranal, Chile, begins operation on September 3. It consists of four 8.2-m (323-in.) mirrors, each with its own name (Antu, Kueyen, Melipal, and Yepun) that initially operate independently, but will be linked with interferometry starting in 2001. *See also* 1998 AST.

Gemini South, the exact twin of Gemini North on Mauna Kea, Hawaii, begins operations at Cerro Pachón, Chile. *See also* 1999 AST.

AMANDA (Antarctic Muon and Neutrino Detector Array) begins a large-scale test of concept at the South Pole. Nine strings of 302 photomultipliers are each buried from 1300 m to 2400 m (4265 ft to 7875 ft) deep in the ice. The transparent ice exhibits Cerenkov radiation (a flash of light) whenever

a muon is produced by collision with a high-energy neutrino. *See also* 1996 AST.

❖ Biology

Celera Genomics, led by Craig Venter, and the Human Genome Project each publish the "First Draft of the Human Genome." In it, 97 percent of the DNA is sequenced. *See also* 1999 BIO.

An international team of biologists sequences the genome of a flowering plant, *Arabidopsis thaliana*, the first flowering plant all of whose genes have been found. *See also* 1999 BIO.

Craig Venter and coworkers publish almost the entire genome of *Drosophila melanogaster*, the fruit fly that has long been one of the most common subjects of genetic research.

In October biologists who had searched forests of West Africa in vain declare Miss Waldron's red colobus monkey extinct — the first large primate to become extinct since 1800. *See also* 1987 ECOL.

▷ Chemistry

Scientists at the Dubna Institute in Russia create element 116.

Leonid Khriachtchev from the University of Helsinki in Finland reports the first known stable compound of the inert

(or noble) gas argon, argon fluorohydride (HArF). *See also* 1962 CHEM.

Chemists at the Naval Research Laboratory in Washington, DC, produce samples of octanitrocubane, a long-sought hydrocarbon derivative expected to be the most powerful non-nuclear explosive.

David Liu and coworkers at Harvard University in Cambridge, Massachusetts, begin developing a method for producing specific organic compounds that uses single-stranded DNA as a catalyst. This method is successful with organics that otherwise react only with each other at very high concentrations. By 2003 they will have developed 65 related compounds this way and 65 different template DNA strands to create them.

⌚ Communication

New standards — Bluetooth, Wireless Application Protocol (WAP), and General Packet Radio System (GPRS) — fuel development of wireless communications from computer to computer, from computer to handheld devices, or even from computer to appliances.

💻 Computers

Penetration of personal computers in the United States exceeds half of all households. *See also* 1975 COMP.

The Human Genome Project

In 1984 Robert Sinsheimer, then chancellor of the University of California at Santa Cruz, proposed what became the Human Genome Project. Although the main impetus came from the U.S. Department of Energy seeking a big project to keep its money flowing, the idea was basically good whatever the motives. By then scientists knew that every organism is defined by a set of combinations of triplets of four chemical building blocks, called bases, which are carried in every cell on long molecules of deoxyribonucleic acid (DNA). Stretches of this molecule (not necessarily contiguous) are genes, which encode proteins and less often RNA. The total group of all the genes for an organism is called its genome. The Human Genome Project has determined the complete sequence of about 3,000,000,000 bases in human DNA. The DNA bases are usually known by their abbreviations, T, G, C, and A; thus, the result of the Human Genome Project is a giant string of the letters T, G, C, and A, which would fill more than 500 volumes of a large encyclopedia. Scientists intended to identify all the genes in that sequence and to determine what the immediate purpose of each is.

The National Center for Human Genome Research was instituted on January 3, 1989, and with the participation of both the U.S. Department of Energy and National Institutes for Health became the Human Genome Project in 1990. Scientists from the European Union, Japan, and China also participated, forming with the Human Genome Project an international Human Genome Organization (HUGO). Meanwhile, on May 8, 1998, a corporation known as Celera, then run by Craig Venter, announced that they too would sequence the human genome and do so faster than the Human Genome Project. The race was on, and with competition, the goals were reached sooner for both competitors.

When, on June 25, 2000, President Bill Clinton of the United States, Prime Minister Tony Blair of the United Kingdom, and Craig Venter of Celera Genomics jointly announced the completion of decoding all the bases that make up the genes in a human, many assumed that the Human Genome Project had finished deciphering all human genes. The actual first completion for the whole sequence had occurred on June 23, when Celera's computers joined their data in a rough sequence — which prompted the big announcement so that the government project would not appear to have been beaten. In fact, later analysis of the Celera map suggested that this first draft contained many errors. The actual end of the project came in 2003. On April 15, the 50th anniversary of the publication of the structure of DNA by James Watson and Francis Crick, the Human Genome Project announced the conclusion of the project with more than 99 percent of the human genome decoded.

Along the way, the genomes of organisms other than human have been sequenced. Even before the Human Genome Project had been instituted, scientists had sequenced the genomes of many viruses, which are much smaller and simpler than creatures with cells. Celera achieved the first bacterium, *Haemophilus influenzae*, in 1995. Since then, bacteria that cause syphilis, chlamydia, tuberculosis, cholera, and staph infections, among some 60 different bacteria, have all had their genomes sequenced. In 1996 the gene of yeast, the first protist, was added to the list. The mosquito that carries malaria, *Anopheles gambiae*, and two of the protists that cause the disease, *Plasmodium falciparum* and *P. yoelii*, also had their genomes sequenced in 2002. After diseases, one set of targets will be the genomes of food crops, starting with rice. Farm animals and pet genomes have been sequenced also.

Scientists also targeted their main experimental organisms. Teams from the United States and Britain completed the genome of the first animal, *Caenorhabditis elegans*, a nematode worm, at the end of 1998. Celera concentrated on the fruit fly, *Drosophila melanogaster*, and established its sequence of 1,800,000,000 bases by September 9, 1999. In plants, the first success came at the end of 2000 with the mustard *Arabidopsis thaliana*, the common laboratory plant for botanists. In October 2001, sequencing of the genome of the Japanese pufferfish was finished, the first fish. An international consortium had produced 98 percent of the map for the laboratory mouse genome by August 2002, but it does not expect to have the complete sequence until 2005. The mouse genome is considered to be nearly as significant as that of the human because of its common use in laboratory studies and a comparatively close relationship to humans — our common ancestor was only about 100,000,000 years ago. Other laboratory animals will be next — the rat and the zebrafish. The chimpanzee, thought to be genetically nearly identical to humans, is also being studied.

Although the announcements in 2000 and 2003 marked major milestones in biology, decoding the bases was actually just a step along the way. One of the surprises was that there appear to be only about 30,000 human genes — about a third of what had been expected before the sequencing was accomplished. Ultimately other questions will need to be resolved, such as how genes interact with each other and with other molecules in the body. The number of proteins encoded is much greater than the number of genes, so one new goal for researchers is to determine all the proteins — known as the proteome. Another task is identification of variations from human to human, called single-nucleotide polymorphisms (SNPs). Such variations are thought to be behind susceptibility to such complex diseases as cancer, diabetes, cardiovascular syndromes, and some types of mental illnesses.

⊕ Earth science

John Horner of the Museum of the Rockies in Bozeman, Montana, and coworkers discover the fossilized parts of five separate *Tyrannosaurus rex* dinosaurs, a 35 percent increase in the number of individuals collected of this famous species. *See also* 1990 EAR.

Michael R. Rampino of New York University and coworkers find evidence that Earth's largest mass extinction, known as the Late Permian, occurred during a period of less than 8000 years some 250,000,000 years ago, killing 95 percent of all species in the oceans. Analysis of sediments at the Permian-Triassic boundary by geochemist Luann Becker of the University of Washington in Seattle demonstrates that these had an extraterrestrial source, implying that the extinction was caused by the impact of a comet or asteroid. *See also* 1980 EAR.

On March 25 the United States launches *IMAGE* (*Imager for Magnetopause-to-Aurora Global Exploration*), the first satellite dedicated to imaging completely Earth's magnetosphere.

Russia launches the European Space Agency's four spacecraft that together are known as *Cluster II*, launching two on July 16 (*Salsa/Samba*) and two more on August 9 (*Rumba/Tango*). These maintain positions at the vertices of a pyramid while they orbit Earth, from which they study interactions of Earth's magnetic field with the solar wind.

⊕ Ecology & the environment

The U.S. National Research Council concludes that Earth's surface temperature is rising

as a part of global warming, but that the lower atmosphere is not affected at this time. *See also* 1999 ECOL; 2001 ECOL.

⊖ Electronics

Jack Kilby, Zhores I. Alferov [b. Vitebsk, Belorussia, Soviet Union, March 15, 1930], and Herbert Kroemer [b. Weimar, Germany, August 25, 1928] are awarded the Nobel Prize in physics — Kilby for contributing to the development of the integrated circuit and Alferov and Kroemer for their invention of components called heterostructures, used in high-speed optical and electronic devices. *See also* 1958 ELEC.

⊖ Food & agriculture

The U.S. National Academy of Sciences issues a report urging caution concerning growing and using genetically engineered food, although noting that no gene-modified food being sold at this time poses any actual threat. *See also* 1993 FOOD.

◊ Materials

Alan Heeger, Alan MacDiarmid, and Hideki Shirakawa are awarded the Nobel Prize in chemistry for the discovery and development of plastics that conduct electricity. *See also* 1977 MATR.

Σ Mathematics

A new exact solution to the three-body problem, developed by Richard Montgomery of the University of California, Santa Cruz, and Alain Chenciner of the Bureau of Longitudes in Paris, shows that bodies of near equal sizes can orbit each other in a figure-8 pattern where each body in turn passes between the other two.

A computer at the University of Giessen in Germany verifies to 400,000,000,000 the 1742 conjecture of Christian Goldbach that every even number greater than 2 is the sum of two primes. *See also* 1742 MATH.

♥ Medicine & health

The first robot surgery, the removal of a gallbladder, is performed in Richmond, Virginia, using the da Vinci Surgical System.

Researchers from the University of Alberta in Edmonton, Canada, report that transplants of insulin-producing cells from cadavers into persons with type I diabetes free patients from the need for insulin injections. The patients do have to maintain a lifetime of drugs to suppress immune reactions that would destroy the transplanted cells.

French scientists report success in relieving babies of a severe immune disorder (a hereditary lack of T cells) through the use of gene therapy that infuses working copies of marrow stem cells into their bones. Later, however, some recipients will develop a form of leukemia. *See also* 1990 MED.

Paul Greengard [b. New York City, December 11, 1925], Eric R. Kandel [b. Vienna, Austria, November 7, 1929], and Arvid Carlsson [b. Uppsala, Sweden, January 25, 1923] are awarded the Nobel Prize in physiology or medicine for their discoveries of how brain cells send signals to each other and how this affects mental processes.

⊗ Physics

A collaboration of 54 physicists working at the DONUT

(Direct Observation of the Nu Tau) detector announce they have obtained the first direct evidence of the tau neutrino, previously shown to exist by indirect evidence. The evidence suggests that they have detected four of the elusive tau neutrinos. *See also* 1975 PHY.

Researchers in Japan announce a shortfall in the number of muon neutrinos beamed from the Japanese Accelerator Facility (KEK) at the Super-Kamiokande neutrino telescope. Although 40 muon neutrinos should have been detected, 13 neutrinos were missing and were presumed to have changed flavor — that is, become electron neutrinos or tauon neutrinos instead of the muon variety. *See also* 1998 PHY.

Experiments at the Italian National Research Council in Florence and at the NEC Research Institute in Princeton, New Jersey, demonstrate that interference patterns can propagate faster than the speed of light.

↗ Transportation

Permanent occupation of the *International Space Station* begins on May 19. *See also* 1998 TRAN.

2001

◀ Anthropology

Meave Leakey and coworkers discover the fossil from about 3,500,000 years BCE of a previously unknown hominid, which they name *Kenyanthropus platyops* ("flat faced man from Kenya").

In Ethiopia Yohannes Haile-Selassie [b. Adigrat, Tigray, Ethiopia, February 23, 1961] discovers the fossil of a forest-

dwelling subspecies of *Ardipithecus ramidus* that lived 5,800,000 years BP, the earliest hominid discovered to this date. The subspecies is named *Ardipithecus ramidus kadabba*, a name based on words from the local language of the Afar region — *Ardi* meaning floor, *ramidus* root, and *kadabba* oldest ancestor (*pithecus* is derived from the Greek for *ape*). See also 1997 ANTH.

■ Archaeology

Timothy Heaton discovers a bone tool in a cave on Prince William Island off the coast of Alaska that is carbon-14 dated at 10,300 BCE, establishing a human presence along the coast. This, along with a skeleton found in the same cave in 1997 and dated at 9200 years BCE, suggests that a seafaring people were traveling along the west coast of North America during this period. See also 2003 ARCH.

Despite closing Lascaux Cave to visitors in 1963 and using formaldehyde to prevent the growth of a green alga that was covering the famous cave paintings, the paintings begin to suffer a new invader in June of this year — a fungus this time, *Fusarium solani*.

Although a fungicide slows its growth, the fungus is infected with a bacterium, *Pseudomonas fluorescens*, which also causes damage and which must be attacked with an antibiotic. Getting this problem under control leads to other invasions of similar combinations. Scientists will get the fungus under control by March 2003. See also 1963 ANTH.

★ Astronomy

The *Hubble Space Telescope* (HST) observes the atmos-

sphere of the exoplanet HD 209484b as the planet passes in front of its star. It is the first direct observation of an extra-solar planet; HD 209484b, which is about 0.7 the mass of Jupiter, had been originally detected by the change in position of the star as the planet orbited in an orbit one-eighth the distance from the star as Mercury is from the Sun. The observations by HST revealed trace elements of sodium in the atmosphere. See also 2002 AST.

Geoffrey Marcy and R. Paul Butler announce the discovery of an extrasolar planet slightly smaller than Jupiter orbiting star HD 4028 at a distance about equal to that of Mars about the Sun, suggesting a system of planets similar to the solar system might exist about HD 4028.

Timothy Beers [b. Lafayette, Indiana, June 24, 1957] of Michigan State University and coworkers use uranium-238 to establish the ages of the oldest stars in the universe. They determine that these stars are 12,500,000,000 years old (with an uncertainty of 3,000,000,000 years), which provides a minimum age for the universe, which must be older than the oldest stars.

American astronomer Robert Millis announces the discovery of a Kuiper belt object larger than Ceres. Initially named 2001KX76, its diameter is 1200 km (750 mi) and its distance when discovered is 6,500,000,000 km (4,000,000,000 mi). See also 1801 AST; 2003 AST.

The orbit of Comet 200 CR-105 is calculated and found to be distorted as if by the presence of a planet larger than

Pluto orbiting far beyond Neptune, now or at some time in the distant past. One possibility is that the planet could actually have been Neptune if Neptune previously had an orbit farther from the Sun. See also 1930 AST.

Shoemaker Near Earth Asteroid Rendezvous (NEAR Shoemaker), after orbiting and studying the asteroid 433 Eros for a full Earth year, nears the end of its operational fuel. The probe's operators bring it closer and closer to the asteroid, finally landing on it on the asteroid on February 12 — the first object from Earth to land on an asteroid. See also 2000 AST.

On April 7 the United States launches *Mars Odyssey*, which enters orbit about the Red Planet on October 23. Its primary mission will be to search for water.

On June 30 the United States launches the *Microwave Anisotropy Probe* (MAP), which will measure temperature fluctuations in the cosmic microwave background with unprecedented precision. It goes into solar orbit at the L2 Lagrangian point, which keeps it 1,600,000 km (1,000,000 mi) from Earth. Data from this mission will help determine when galaxies formed and also the ratios of observable mass to dark matter to dark energy in the universe. See also 1995 AST.

On August 8 the United States launches *Genesis*, which will spend three years orbiting the Sun, collecting particles of the solar wind. It will then return the material to Earth.

❖ Biology

Researchers discover that the common mineral calcite (cal-

cium carbonate) tends to segregate left-handed amino acids on one face and right-handed ones on another, suggesting a possible origin for amino acids in living organisms, all of which are left-handed. Similarly, the handedness of amino acids affects crystal formation in calcite.

The United States experiences its first apparent bioterrorism attack. Letters containing finely milled spores of the anthrax bacteria *Bacillus anthracis* are mailed, resulting in five deaths.

Researchers studying the draft of the human genome conclude that humans have only about 30,000 genes, far fewer than the 100,000 to 200,000 genes expected before the genome was mapped and not many more than in the nematode *C. elegans*. See also 2000 BIO; 2003 BIO.

Scientists in Kenya and at the U.S. National Cancer Institute show that genetic differences are so large between Africa's savanna elephants and forest elephants that they are different species.

A cat is cloned for the first time at Texas A&M University.

Leland H. Hartwell [b. Los Angeles, California, October 30, 1939], R. Timothy Hunt [b. Neston in the Wirral, England, February 19, 1943], and Paul M. Nurse [b. London, January 25, 1949] are awarded the Nobel Prize in physiology or medicine for their discoveries about the cell cycle, the process by which cells grow and divide.

❖ Chemistry

Jun Akimitsu of Aoyama Gakuin University in Tokyo

and coworkers discover that the common compound magnesium diboride is a superconductor at temperatures as high as 39 K (-234°C , or -389°F), considerably higher than that of other simple materials (although not as high as some of the complex ceramics). *See also* 1986 PHY.

William S. Knowles [b. Taunton, Massachusetts, June 1, 1917], Ryoji Noyori [b. Kobe, Japan, September 3, 1938], and K. Barry Sharpless [b. 1941] are awarded the Nobel Prize in chemistry for their discoveries of catalysts that enable chemists to create chemicals that are preferentially left-handed or right-handed.

■ Construction

The twin towers forming the World Trade Center in New York are destroyed by the impact of hijacked planes piloted by terrorists whose clear intent is to ram into the towers. At the same time, another plane hijacked by the same group crashes into the Pentagon in Arlington, Virginia. A fourth hijacked airplane crashes in Pennsylvania, apparently because the passengers fought against the hijackers, who are thought to have had another building in Washington, DC, as the target.

■ Earth science

Maurice Bluestein of Indiana University-Purdue University and Randall Osczevski of the Defense and Civil Institute of Environmental Medicine in Toronto, Canada, develop an adjusted wind-chill-factor scale based on experiments with human volunteers and

measurements of wind speed at face level, which is usually less than that measured by anemometers. This scale, the Wind Chill Temperature Index, is adopted November 1 by both the U.S. National Weather Service and the Meteorological Services of Canada. *See also* 1959 EAR.

A fossil of a dromaeosaur dinosaur with feathers and a long reptilian tail from 130,000,000 years BP is found in the Liaoning, China, fossil beds, but will not be announced until March 2002. The feathers are clearly imprinted into the rock, convincing most scientists that feathers evolved with dinosaurs rather than with birds, widely believed to be the living descendants of the dinosaurs. The feathered dromaeosaur lived some 20,000,000 years after the first known bird, however. *See also* 1998 EAR.

Johannes G.M. Thewissen and his team describe the discovery of two early whale ancestors, terrestrial mammals that lived 50,000,000 years ago: the fox-size *Ichthyolestes* and the wolf-size *Pakicetus*.

On December 7 the United States in cooperation with France launches the satellite *Jason 1*. It will monitor ocean circulation and help determine the relation between the oceans and the atmosphere, as well as follow such events as the El Niños. *See also* 1982 EAR.

On December 7 the United States launches *TIMED* (*Thermosphere-Ionosphere-Mesosphere-Energetics and Dynamics*), a satellite that gathers data on the influence of the Sun and humans on the upper atmosphere.

■ Ecology & the environment

Studies in the Amazon rain forest and the cloud forests of Central America show that deforestation changes the climate so much that both these ecosystems could disappear in a short period of time, perhaps in three decades, if their extent is reduced so much that the feedback cycle is broken.

The Intergovernmental Panel on Climate Change, established by the United Nations, reports in January that greenhouse gases produced mainly by the burning of fossil fuels "contributed substantially to the observed [global] warming over the last 50 years." *See also* 2000 ECOL.

In February scientists report that global warming is resulting in the loss of snow cover from the peak of Mount Kilimanjaro in Africa and the melting of glaciers in the Andes of South America. *See also* 1999 ECOL.

In March, President George W. Bush withdraws the United States from the Kyoto Protocol climate treaty intended to reduce global warming by reducing the rate of production of carbon dioxide and other greenhouse gases. *See also* 1997 ECOL.

In April oceanographers report that the oceans are warming as a result of human activities. *See also* 1999 ECOL.

The Aleutian Canada goose (*Branta canadensis leucoparia*) is removed from the United States Endangered Species List. The Aleutian Canada goose is found on only a few of Alaska's Aleutian Islands and in some areas of California and Oregon. Its decline



LEADING EDGE OF MELTING GLACIER

In most regions around the world, glaciers, which form wherever more snow regularly falls each winter than melts over the summer, have begun to melt faster than they form because of global warming. Many glaciated regions of the 20th century are expected to lose all their glaciers by 2020, including the U.S. Glacier National Park, as well as Mount Kilimanjaro in Africa and many mountains in South America.

began with the introduction of foxes on the islands where the geese breed by trappers who wanted to harvest the foxes for their fur. The fox, a new predator to the Aleutians, completely eradicated the goose populations on every island but one (which had no foxes introduced). Biologists, beginning in 1967, worked to eliminate foxes from the islands, followed by reintroducing geese to the islands. *See also* 1995 ECOL.

■ Electronics

Various researchers, by crossing carbon nanotubes or by diluting molecules called thiolos with nonconductors, create transistors consisting of single nanotubes. *See also* 1999 MATR; 2003 MATR.

Yong Chen of Quantum Science Research (Hewlett-Packard) invents a manufacturing method, called nano-imprint lithography, that can produce molecular-scale circuits on computer chips. Platinum wires formed

by electron-beam lithography form a master mold on which a single layer of electronically switchable molecules is deposited. A second grid of wires is placed orthogonal (wires are at right angles to each other) to the first. Wire junctions less than a square micrometer can be addressed and used to read or write data.

S Mathematics

Isaac Chuang and his team at Stanford University and IBM's Almaden Research Center demonstrate the use of a simple quantum computer for applying Peter Shor's quantum factoring algorithm. *See also* 1994 MATH.

♥ Medicine & health

Self-contained artificial hearts (with no components outside the body) called AbioCors are implanted in clinical trials on July 2 and September 13. *See also* 1990 MED.

U.S. President George W. Bush restricts federal payments to support research into embryonic stem cells to use of those lines or stem cells already started (that is, to viable daughter cells descended from a cell previously harvested from embryonic tissue). Embryonic stem cells are thought to be important to developing cures to several chronic and debilitating diseases. *See also* 1998 MED; 2002 MED.

On September 13 doctors in Boston correct a heart defect, hypoplastic left-heart syndrome, in an unborn fetus. The boy is born healthy some 11 weeks later. Untreated cases of this disease result in death shortly after birth. *See also* 1999 MED.

*** Physics**

Scientists at the Sudbury Neutrino Observatory detect an important shortfall in electron neutrinos coming from the Sun — the strongest indication yet that neutrinos oscillate from one type to another as they travel. In Japan, the Super-Kamiokande detector, whose earlier results indicated that neutrino types oscillate between electron, muon, and tauon types, detects 44 neutrinos coming from the KEK laboratory, while 64 were expected, confirming earlier results. The theory of oscillation also implies that neutrinos that oscillate must have mass. *See also* 2000 PHY.

Scientists at Brookhaven National Laboratory smash the nuclei of gold atoms into a gold target, producing what appears to be a quark-gluon plasma, thought to be the first such state of matter on Earth.

Two groups of researchers use slightly different methods to stop a light wave, or photon, and store it for as much as a millisecond in an atomic gas. Lene Hau of Harvard University and coworkers store the light wave in very cold atomic sodium gas, while Ron Walworth and coworkers at the Harvard-Smithsonian Center for Astrophysics store the photons in a vapor of warm rubidium atoms. The light beam after stopping momentarily can be restarted without changing its characteristics. *See also* 1999 PHY.

Eric Cornell, Wolfgang Ketterle, and Carl Wieman are awarded the Nobel Prize in physics for their creation of Bose-Einstein condensates (BECs), a new state of matter, adding BECs to the short list

of solid, liquid, gas, and plasma states. *See also* 1995 PHY.

→ Transportation

After a February 7 launch, the space shuttle *Atlantis* (crew: Kenneth Cockrell, Robert Curbeam, Jr., Marsha Ivins, Thomas Jones, and Mark Polansky) delivers a science laboratory to the *International Space Station (ISS)*, the first of a half dozen U.S. flights and two Russian trips to *ISS* this year. *Atlantis* returns on July 12 carrying Michael Gernhardt, Charles Hobaugh, Janet Kavandi, Steven Lindsey, and James Reilly. The mission delivers and installs the Quest Airlock on *ISS*.

Discovery is launched on March 8 with a crew consisting of James Kelly, Paul Richards, Andrew Thomas, and James Wetherbee for *ISS* resupply, lab outfitting, and crew exchange. Another crew exchange starts with the August 10 *Discovery* launch, bringing Daniel Barry, Patrick Forrester, Scott Horowitz, and Frederick Sturckow to the space station.

The year's first launch of *Endeavour* is on April 19, with Jeffrey Ashby, Scott Parazynski, John Phillips, Kent Rominger, Chris Hadfield (Canada), Umberto Guidoni (Italy), and Yuri Lonchakov (Russia) as the international crew. The mission attaches Canadarm2, a robotic arm, to *ISS*. A final crew exchange begins on December 5, when *Endeavour* lifts Linda Godwin, Dominic Gorie, Mark Kelly, and Daniel Tani to *ISS*.

Russian space vehicle *Soyuz TM 32* is launched on April 28 to bring a crew of Yuri Baturin, Talgat Musabayev, and Dennis

Tito (United States), the first space tourist, to *ISS*. The *Soyuz* emergency vehicle is exchanged, so the crew returns on *Soyuz TM 31*. On October 21 *Soyuz TM 33*, carrying Viktor Afanasyev, Konstantin Kozeev, and Claudie Haignere (ESA) lifts to *ISS* to conduct experiments in materials research, life sciences, and meteorological phenomena. Again the emergency vehicle is exchanged, so the crew returns on *Soyuz TM 32*.

After 15 years in space, the Russian space station *Mir* is abandoned and plunges into the Pacific Ocean.

2002

◀ Anthropology

Michel Brunet and Martin Pickford discover in Chad the oldest hominid fossil found so far, the skull of a species named *Sahelanthropus tchadensis* who lived 6,000,000 to 7,000,000 years BP in a setting of woods broken with patches of savanna. *See also* 1991 ANTH.

A skull found in the former Soviet nation of Georgia, dated at about 1,750,000 years BP, appears more like *Homo habilis* than it does like the other skulls found at the same site. These date from about the same time, but resemble *H. erectus* or *H. ergaster*, which is what might have been expected from fossils of about that time. One surprise for all of these skulls is their location, since it had been believed that hominids had not emigrated to Europe from Africa this early. *See also* 1995 ANTH.

▲ Archaeology

In a first for archaeology, Julio Mercader and coworkers

recover stone tools that had been used by chimpanzees for cracking nuts some years in the past. *See also* 1960 ANTH.

The famous Altamira painted caves are closed to the public because of the impact of carbon dioxide and water vapor exhaled by human visitors on organisms that can grow on cave walls; these are destroying paintings thousands of years old. *See also* 1879 ANTH.

★ Astronomy

Further analysis of data from the orbiting *Mars Odyssey* space probe reveals in March clear signs of large amounts of water ice in the polar regions of Mars. The radiation detectors on *Mars Odyssey* detect hydrogen by examining neutrons kicked up by cosmic rays, neutrons whose most probable origin was in hydrogen nuclei. The ice is thought to be prevented from evaporating by having its upper layer covered with dust. *See also* 2000 AST.

An international team by comparing the number of gravitational lenses observed during a ten-year period to the total number of galaxies finds new and independent evidence for the existence of dark energy, a mysterious force that is speeding up the expansion of the universe. *See also* 1998 AST.

Kenneth R. Sembach and coworkers report studies based on *FUSE (Far Ultraviolet Spectroscopic Explorer)* satellite observations show that the Milky Way is enveloped in a huge cloud of hot gas that extends almost to the nearest galaxies.

Studies of meteorites blasted off the surface of the Moon

that have landed on Earth indicate that asteroids, not comets, bombarded the Moon (and Earth as well) about 3,900,000,000 years ago, causing thousands of giant craters. *See also* 1982 AST.

NASA scientists propose that an unusual astronomical object named RXJ1856.6-3754 is a “quark star,” a body so dense that the atomic nuclei have broken into constituent up and down quarks as well as some strange quarks.

A dozen unusual radio sources that appear as X patterns formed by giant jets of hot matter and radiation are recognized as the results of pairs of black holes colliding and merging. Also, astronomers discover a double black hole in the galaxy NGC 6240. *See also* 1980 AST.

On February 5 the United States launches *RHESSI* (the *Reuven Ramaty High Energy Solar Spectroscopic Imager*). It explores the basic physics of particle acceleration and energy release during solar flares.

On October 4 and again on December 11, signals from the *High-Energy Transient Explorer II (HETE II)* satellite alert optical telescopes on Earth of gamma-ray bursts that are then successfully observed, the second and third such bursts to be seen optically. The earliest observation, on December 11, came less than two minutes after the blast. *See also* 1999 AST.

The Atacama Large Millimeter Array (ALMA) radio telescope in Llano de Chajnantor, Chile, which combines 64 antennas, each 12 m (39 ft) wide, begins operation. It is part of the worldwide network of radio

telescopes that can be used together for very long baseline interferometry.

In September the laser-based LIGO telescope intended to detect gravity waves begins operation with its first run of 17 days. No gravity waves are found, but none had been expected at the accuracy of the first run. As the equipment is further calibrated and sensitivity improved, astronomers expect to detect gravity waves caused by infalling matter on binary neutron stars, certain kinds of pulsars, or even background radiation from the big bang.

The ANTARES (Astronomy with a Neutrino Telescope and Abyss Environmental Research) project begins in the Mediterranean Sea off the coast of France. Ten vertical strings of about 1000 photomultiplier tubes each, with each string about 400 m (1300 ft) long, are suspended vertically from the bottom of the sea at a depth of about 2500 m (8000 ft) at intervals of about 60 m (200 feet). These observe Cerenkov radiation (flashes of light) produced by high-energy neutrinos generated by accelerated protons in space.

Raymond Davis, Masatoshi Koshiba, and Riccardo Giacconi are awarded the Nobel Prize in physics for the development of new windows on the universe and discoveries made with them. Davis pioneered the concept and creation of a neutrino telescope and used the first such device to study solar fusion, while Koshiba developed an improved neutrino telescope that not only confirmed the result of Davis's experiment, but also was the first neutrino telescope to detect a supernova.

Giacconi recognized the potential of capturing X rays from space and became the first to observe X rays from beyond the solar system with the first X-ray telescopes, which he built and launched into space. Among his discoveries are X-ray sources now believed to be the first black holes ever observed. *See also* 1988 AST; 1987 AST; 1962 AST.

❖ Biology

Two groups of geneticists publish draft sequences of the rice genome of two rice varieties.

An international consortium publishes the genome of *Anopheles gambiae*, the mosquito vector of malaria, while other groups publish the genomes of two of the plasmodia that actually cause the disease.

For the first time in 87 years, a group of insects is assigned its own order (on a par with Lepidoptera for butterflies and moths). The new order, Mantophasmatodea, includes two genera and three species, popularly named gladiators, that are somewhat like a cross between a mantis and a grasshopper. *See also* 1995 BIO.

Scientist locate a fifth taste receptor on the tongue, which responds to amino acids (including the glutamate of monosodium glutamate). Previously it was thought that there were only taste receptors for sweet, salt, bitter, and sour. Also, a nerve receptor that detects cold is found for the first time; it is also activated by menthol. Other cold receptors not yet located are thought to be part of the sensory system as well.

Experiments conducted by two different groups of scien-

tists show that amino acids, the building blocks of proteins, could form naturally in outer space from the action of ultraviolet radiation on simple, common molecules such as water, ammonia, and methanol. *See also* 1953 BIO.

John B. Fenn [b. New York City, 1917], Koichi Tanaka [b. Toyama City, Japan, August 3, 1959], and Kurt Wüthrich [b. Switzerland, October 4, 1938] are awarded the Nobel Prize in chemistry for developing ways to analyze very large biological molecules. Before their work, biochemists needed to spend years of effort to determine the mass of and to locate the atoms and their placement in a large molecule, such as a protein. Proteins are large molecules that are folded in specific ways; the folded shape is essential to the protein's function.

Sydney Brenner [b. South Africa, January 13, 1927], H. Robert Horvitz [b. America, May 8, 1947], and John E. Sulston [b. England, March 27, 1942] are awarded the Nobel Prize in physiology or medicine for their discoveries concerning organ development and apoptosis, or programmed cell death — the normal process by which healthy cells self-destruct, thereby maintaining the appropriate number of cells in an organism's tissues.

Chemistry

Scientists in Rome create molecules consisting of four nitrogen atoms — molecules of nitrogen in air contain two atoms only.

Computers

A new Japanese supercomputer called Earth Simulator

achieves a processing speed of 35,600 gigaflops (a gigaflop is a billion calculations per second). This is five times faster than its nearest competitor. *See also* 1997 COMP.

Earth science

Laboratory studies reveal that Earth's mantle (the layer between the crust and core) could hold five times as much water as is in all the oceans.

Grant Yip of the University of California, Santa Barbara, and coworkers discover evidence of massive landslides in Baja California that occurred at precisely the same time as a giant object struck the Yucatán peninsula on the other side of the continent. The landslides were triggered by a magnitude 13 earthquake, thought to have been caused by the impact. *See also* 1991 EAR.

On March 17 the United States in consort with Germany launches GRACE (*Gravity Recovery and Climate Experiment*), two Earth-orbiting satellites flying in tandem to make extremely precise measurements of Earth's gravitational field.

Ecology & the environment

A U.S. Geological Survey study reveals that U.S. waterways are contaminated with steroids, ingredients used in plastics, detergents, insect repellent, and antibiotics; the greatest concerns are over high levels of estrogen and 22 different antibiotics, which may directly affect the health of organisms.

Electronics

Researchers at Princeton University discover a new method

for making computer chips based on molding them with etched quartz instead of "burning" them through masks.

Materials

Researchers at the University of California, Davis, discover that distributing molecules of gadolinium nitrate through porous silicon creates a form of silicon that explodes like gunpowder when scratched or when exposed to a spark from a low-power battery. *See also* 1990 MATR.

Mary P. Ryan of Imperial College of Science, Technology, and Medicine in London discovers that stainless steel develops pit corrosion because chromium atoms in the alloy migrate to zones that are then surrounded by regions of low chromium. Corrosion could be halted cheaply by processes that distribute chromium atoms uniformly on the steel's surface. *See also* 1911 MATR.

Arthur J. Epstein and Joel Miller at Ohio State University report a plastic material containing magnesium that becomes magnetic when illuminated with blue light; it loses its magnetism partially when illuminated with green light.

Mathematics

Manindra Agrawal, Neeraj Kayal, and Nitin Saxena publish a deterministic polynomial-time algorithm that checks whether a number is prime. *Polynomial time* means that the time taken to solve a problem by a computer increases with complexity of the problem at a rate similar to that of the increase of a polynomial or, essentially, the increase of a fixed power of a number. This

is contrasted with *exponential time*, which increases much faster since the power of the number itself increases. *See also* 1980 MATH.

Preda Mihailescu of the University of Paderborn, Germany, proves Eugène Catalan's 1844 conjecture that 8 and 9 are the only examples of consecutive whole numbers that are also powers (8 is the cube of 2 and 9 is 3 squared).

Medicine & health

A Swedish study suggests that potato chips, French fries, and other foods cooked at high temperatures contain high levels of the potential carcinogen acrylamide.

A trial with an experimental vaccine against human papillomavirus-16, the cause of cervical cancer, shows that it is 100 percent effective in a study of 1200 sexually active young women.

In June Ronald McKay and coworkers at the U.S. National Institutes of Health demonstrate with mice that embryonic stem cells coaxed into becoming brain cells cure murine Parkinson's disease. *See also* 2001 MED.

A large-scale study of the effects of hormone replacement therapy in postmenopausal women is halted because the side effects, including increased risk of cancer, heart attacks, strokes, and blood clots, outweigh the benefits, which appear to be slight.

In May David E. Cummings of the University of Washington and the Department of Veterans Affairs in Seattle, Washington, and coworkers identify the hormone ghrelin, which

causes hunger, slows metabolism, and decreases the ability to use fat for energy. In August Stephen R. Bloom of the Hammersmith Hospital at Imperial College School of Medicine in London determines that a second hormone, known as peptide YY_{3,36}, or PYY, which is produced by the small intestine in response to food, switches off hunger in the brain.

Doctors in Saudi Arabia perform the first uterus transplant.

❖ Physics

Scientists at the Sudbury Neutrino Observatory detect an important reaction between neutrinos and deuterium atoms, the “neutral current,” which allows the detection of all three neutrino flavors.

Robert C. Dynes of the University of California, San Diego, and coworkers discover that coating a superconductor with a very thin layer of silver raises the temperature at which it becomes superconducting, although thicker layers have the opposite effect. *See also* 1989 PHY.

Studies of a Fermilab experiment in which a particle called sigma minus is shot into a target reveal signs of previously unknown heavy particles that contain two charm quarks each, called twice-charmed baryons. *See also* 1964 PHY.

Researchers produce the first antimatter hydrogen gas at CERN in Geneva. The international collaboration ATHENA traps positrons and antiprotons in a Penning trap; they combine forming a gas of about 50,000 antihydrogen atoms. *See also* 1995 PHY.

Two teams of physicists discover a new form of radioactivity, the simultaneous emission of two protons from iron-45 nuclei.

➤ Transportation

On March 1 the space shuttle *Columbia*, carrying a crew of Scott Altman, Duane Carey, Nancy Currie, John Grunsfeld, Richard Linnehan, Michael Massimino, and James Newman, is launched to service the *Hubble Space Telescope*. The crew installs a new power unit, new cameras, and new solar arrays.

On April 8 *Atlantis* is launched to continue the assembly of the *International Space Station* (ISS), bringing and installing a central truss segment. The crew is Michael Bloomfield, Stephen Frick, Lee Morin, Ellen Ochoa, Jerry Ross, Steve Smith, and Rex Walheim. *Atlantis* is launched on October 7 with a second truss segment and a crew of Jeffrey Ashby, Sandra Magnus, Pamela Melroy, Piers Sellers, David Wolf, and Fyodor Yurchikhin (Russia).

Russia continues to carry out emergency vehicle exchanges on ISS. *Soyuz TM 34* carries Yuri Gidzenko (Russia), Robertor Vitor (ESA), and Mark Shuttleworth (South Africa, a paying tourist), who all return on *Soyuz TM 33*, which had been left as the emergency vehicle. Similarly, on October 30, *Soyuz TMA-1*, the start of an upgraded series of *Soyuz* vehicles, brings Yury Lonchakov (Russia), Sergei Zaletin (Russia), and Frank DeWinne up to the ISS; they return on *Soyuz TM 34*.

Endeavour is launched on June 5 to provide crew

exchanges and to bring additional equipment to ISS. The crew is Franklin Chang-Diaz, Kenneth Cockrell, Paul Lockhart — all from the United States — and Philippe Perrin (France). They deliver a Microgravity Science Glovebox for use in working with hazardous materials. *Endeavour* returns on November 23 with John Herrington (first Native American in space), Paul Lockward, Michael Lopez-Alegria, and James Wetherbee (all from the United States) as crew and brings a new girder to ISS.

2003

◀ Anthropology

Three skulls of modern humans found by Tim White and coworkers in Ethiopia and reassembled from fragments over six years are described as the earliest modern humans known, dating from between 154,000 and 160,000 BP. This early date and location tends to verify the “out of Africa” theory that modern humans evolved in Africa and displaced other hominid species, such as the Neandertals, when they migrated from Africa to Europe and Asia. Because of some differences in the skulls from today’s *Homo sapiens sapiens*, the new specimens are assigned to a different subspecies, *H. sapiens idaltu* (“elder wise man”). Cut marks on the skulls, the fact that no other skeletal remains are found with the skulls, and wear patterns on the skull of a child suggest that the skulls may have been stripped of their flesh and preserved separately from the bodies. *See also* 1995 ANTH.

In Italy footprints left in volcanic ash of Roccamonfina Volcano some 350,000 years ago and long known to the local population as “devil’s tracks” are found to include those of three hominids who were apparently fleeing from the volcano’s eruption. The tracks are investigated by Marco Avanzini and Paolo Mietto after discovery by local archaeologists. From the well-dated volcanic tuff, the prints must have been made either by *Homo erectus* (a.k.a. *H. ergaster* in African populations) or by *H. heidelbergensis*, the precursor to the Neandertals.

❖ Archaeology

Gary Urton of Harvard University proposes that Inca knotted-string devices called quipu (a.k.a. khipu) encode narratives as well as numbers. His book *Signs of the Inca Khipu* breaks down the existing quipu to their basic elements, which he hopes will be a step toward translation. *See also* 1997 ARCH.

Mark Seielstad of the Harvard School of Public Health, R. Spencer Wells of the University of Oxford, and coworkers claim on the basis of a DNA mutation observed in the Y chromosome of living Siberian and Native American populations that the earliest migration of Asians to the Americas occurred between 15,000 and 18,000 BP — earlier than the traditional date of the Clovis migration (c. 12,000 BP) but later than the 30,000 BP that some revisionist theories have proposed. *See also* 2000 ARCH.

★ Astronomy

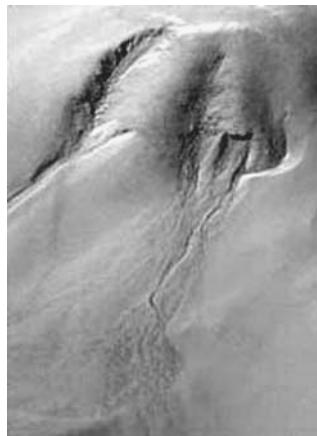
Images obtained with NASA’s *Wilkinson Microwave Anisotropy Probe* (WMAP) confirm *Hubble*

observations for the age of the universe — 13,700,000,000 years — with an accuracy of just 1 percent. The satellite observations also show that the clustering of matter forming the seeds of galaxies took place only 200,000 years after the big bang. Finally, WMAP images suggest that only 4 percent of the universe is ordinary matter; 23 percent consists of dark matter; but 73 percent is dark energy, the force speeding up acceleration of the universe. *See also* 2002 AST.

Philip R. Christensen of Arizona State University proposes that the gullies observed on steep slopes on Mars are caused when snow falls on the tops of these hills. As the snow mixes with dust, it gradually warms, enough to melt the bottom layer. The water flows beneath the snow-dust layer and forms the gully. Gullies become observable when the top layer of snow melts completely. *See also* 2000 AST.

On March 29 an extremely bright gamma ray burst detected by the *High-Energy Transient Explorer II* (*HETE II*) satellite is found to be caused by a superenergetic supernova (termed a hypernova) that leads to a heavy star collapsing all the way to becoming a black hole. Information from the burst tends to confirm a theory that the hypernova shoots out jets at nearly light speed that produce gamma rays from shock waves as they encounter the interstellar medium. *See also* 1997 AST.

Pierre Kervella of the European Southern Observatory in Santiago, Chile, and coworkers discover that the rapidly spinning star Achernar is more than 1.5 times as wide as it is tall, possessing an equatorial bulge so great that its



GULLIES ON MARTIAN SLOPE As successive space probes have revealed better images of the surface of Mars, it has become apparent that some Martian features resemble those formed by water on Earth — although there is no direct evidence of surface water today (except for ice in the polar caps). The gullies shown here have provoked a number of explanations, ranging from brief bursts of water from under a soil layer (like temporary springs) to artifacts produced by dry ice (frozen carbon dioxide) flowing down the slope. Liquid water should evaporate instantly in the thin Martian atmosphere, which makes the appearance of gullies or channels difficult to explain.

internal rotation must be much greater than its surface rotation.

Observations with the *Hubble Space Telescope* interpreted by Alfred Vidal-Madjar of the Astrophysics Institute of Paris and coworkers reveal that exoplanet HD 209484b contains hydrogen in its atmosphere, which it is losing at a considerable rate because the planet orbits very close to its star. Vidal-Madjar and his team find that the star dims by 15 percent at hydrogen wavelengths, which suggests that the giant planet has a tail like a comet. *See also* 2001 AST.

A study of Kuiper belt objects in a small sector of the sky, conducted by the *Hubble Space Telescope* and directed by Gary M. Bernstein of the University of Pennsylvania in Philadelphia, detects only three of the cometlike objects. Since 85 had been anticipated, the astronomers involved conclude that there must be some additional source of short-period comets, as the implied Kuiper belt number is far too small to supply the comets observed. *See also* 2001 AST.

Rodrigo A. Ibata of Strasbourg Observatory in France discovers a dwarf galaxy in Canis Major that is being absorbed by the Milky Way.

The Large Zenith Telescope (LZT) at the Liquid Mirror Observatory at the University of British Columbia in Vancouver, Canada, begins operation. The LZT uses a base 6 m (246 in.) in diameter filled with 30 L (7.9 gal) of liquid mercury that rotates at 7 rpm to achieve a parabolic reflector. The reflector always looks straight up, since it depends on gravity and angular momentum to achieve the parabolic surface of mercury.

Pioneer 10, launched in 1972 to explore the solar system, stops transmitting radio signals when it reaches a distance of 7,600,000,000 miles and signals take 11 hours and 20 minutes to reach Earth.

Jean-Pierre Luminet, Jeffrey R. Weeks, Alain Riazuelo, Roland Lehoucq, and Jean-Philippe Uzan use data from the *Wilkinson Microwave Anisotropy Probe* to produce a model of a finite universe that is a Poincaré dodecahedral space — similar to a soccer ball in many ways. If further study

confirms this view, light (or anything else) traveling through one wall of the universe passes through it and emerge as incoming light from the other side of the universe.

Biology

On April 15, the 50th anniversary of the publication of the structure of DNA by James Watson and Francis Crick, the Human Genome Project announces that the analysis of human DNA is complete and the project is concluded. The project, which took 13 years (originally scheduled to take 15), determined 99.02 percent of the working part of all 23 pairs of human chromosomes, some 2,900,000,000 base pairs. *See also* 2001 BIO.

Francesco Nardi and coworkers at the University of Siena, Italy, use DNA analysis to show that one hexapod (six-legged) group, the Collembola, or springtails, diverged from the insect line even before lobsters and crabs did. The springtails' development of a matching body plan to insects is likely the result of convergent evolution rather than direct ancestry. Previously, most biologists assumed that the six-legged arthropods had evolved once, making the springtail a primitive kind of insect.

Bruce Lyon of the University of California, Santa Cruz, establishes not only that the American coot, a common water bird, can count the number of its eggs but also that wild coots use this ability to moderate their clutch size. Coot hens can sometimes recognize eggs laid in their nests by other coots and reject the nonfamily eggs. Coots that recognize nonfamily eggs lay the same number of eggs as

they normally would, then later dispose of the eggs that are not theirs. Coots that fail to recognize others' eggs count them as part of the clutch and stop laying their own eggs (and also fail to eliminate the other eggs).

Both a mule and a horse are cloned for the first time.

Bacteria called rhizobia, which take nitrogen from the air and make it usable for plants, are commonly found in nodules on the roots of legumes such as peas and beans. Three different groups of researchers locate the specific receptors on the root hairs of legumes that determine which bacteria are acceptable for their nitrogen-fixing ability and which should be rejected.

Two studies demonstrate that sleep has an important role in converting short-term memories into long-term versions, with sleep periods after learning producing an average 18 percent increase in retention of data.

The National Human Genome Research Institute completes sequencing the genome of the chimpanzee, which is 98.8 percent the same as the human genome. Researchers at Celera identify specific differences between human and chimp genes for smell, hearing, and other processes.

Americans Peter Agre of Johns Hopkins University in Baltimore and Roderick MacKinnon of the Rockefeller University in New York share the Nobel Prize in chemistry for their studies of the molecules that control the flow of substances into and out of cells, Agre for the way cells regulate water intake and flushing, MacKinnon for showing how sodium

and potassium ions pass through a cell's membrane. *See also* 1988 BIO; 1998 BIO.

Communication

Robert A. Hayes and B. Johan Feenstra of Philips Research in Eindhoven, Netherlands, develop a form of e-paper that changes from black to white under electronic control so fast that it may be used for video images. Earlier forms of e-paper use a system of e-ink that can be changed to form any black-and-white image, which remains stable with no further power input, but the images change too slowly to be used for anything but store signs.

Earth science

Marcelo R. Sánchez-Villagra, Orangel Aguilera, and Inés Horovitz discover in Venezuela the first nearly complete fossil of the rodent *Phoberomys pattersoni*, a guinea-pig relative that at 700 kg (1500 lb) was by far the largest known rodent, about the size of a bison.

Asish R. Basu of the University of Rochester in New York discovers in Antarctica pieces of a meteorite that appears to have caused the late Permian mass extinction about 250,000,000 BP. *See also* 2000 EAR.

Ecology & the environment

A study by Jason C. Buchan, Susan C. Alberts, Joan B. Silk, and Jeanne Altmann of wild savannah baboons in Kenya reveals that although females of this species typically engage in mating with multiple partners during periods of fertility, male baboons are able to recognize their own offspring and tend to intervene on the

offspring's side during disputes with other baboons.

Energy

A thermonuclear device called Z at Sandia National Laboratories in Albuquerque, New Mexico, achieves fusion by using a sudden blast of X rays aimed at a tiny capsule of deuterium. The heavy hydrogen then fuses into tritium and helium, producing 10,000,000,000 neutrons with each blast of X rays. *See also* 1986 ENER.

Solar cells with efficiencies as high as 20 percent become commercially available. *See also* 1989 ENER.

Materials

Takashi Saito of Toyota Central Research and Development Laboratories in Nagakute, Japan, and coworkers develop a method for calculating the properties of alloys without forming them. Testing their theory they produce new alloys of titanium that can be deformed more than other alloys and still return to their original shape, that have a low and constant coefficient of expansion, and that, because they are superplastic, can be formed easily into desired shapes at room temperature.

Tobin Marks and coworkers at Northwestern University in Evanston, Illinois, and at Lucent Technologies develop new forms of organic semiconductors based on thiophene units, the exact combination to produce transistors as good as those formed on silicon. The team expects that they will be able to make organic transistors that are faster than silicon ones and that can be laid down on flexible surfaces with the equivalent of ink-jet printers.

Mathematics

On March 13 Daniel A. Goldston of San Jose (California) State University and Cem Y. Yıldırım of Boğaziçi University in Istanbul announce that they have proved that for any rational number greater than zero there are an infinite number of prime pairs closer to each other than that fraction of the average spacing of prime numbers. It has long been known that the average spacing of primes near some number n is the natural logarithm of n . Another way to state this result is that the shortest gaps between primes continue for large numbers, although this does not necessarily mean that there are an infinite number of primes just two units apart (twin primes, such as 3 and 5 or 41 and 43). This result, which on the surface appears as an obscure idea from number theory, actually has deep connections with other parts of mathematics.

On April 3 Jean-Pierre Serre [b. Bages, France, September 15, 1926] receives the first Abel Prize from the Norwegian government. The Abel Prize is intended to provide a mathematics equivalent to the Nobel Prize; the first is accompanied by a cash award of approximately \$800,000. The prize is awarded for lifelong achievement instead of for a specific discovery; in Serre's case this includes work with topology, complex variables, and enumerating the points on algebraic curves over finite fields, including one of the subproofs used in 1995 in Andrew Wiles's proof of Fer-

mat's Last Theorem. *See also* 1993 MATH.

Grigori (Grisha) Perelman of the Steklov Institute in St. Petersburg claims in a November 2002 paper, "The Entropy Formula for the Ricci Flow and Its Geometric Applications," continued in March 2003 as "Ricci Flow with Surgery on Three-Manifolds," that he builds on a 1982 result from Richard Hamilton to prove a generalization of the Poincaré conjecture. The conjecture is the oldest unproved conjecture in topology; it can be expressed as saying that the equivalent to a sphere — that is, the "skin" of a ball — in four dimensions is the only three-dimensional figure that completely surrounds its inner space and that has no holes (is simply connected, as topologists say). Although proof of this conjecture has been widely heralded many times since Henri Poincaré first stated it in 1904, all these proofs have proven to be flawed and have been retracted.

Henry Cohn and Noam Elkies solve part of the sphere-packing problem for 8 dimensions and for 24 dimensions. They prove that for 8 dimensions the kissing number (number of spheres that can touch a given sphere at one time) is 120 and for 24 dimensions it is 196,560. *See also* 1998 MATH.

♥ Medicine & health

A new infection arises in China, an acute form of pneumonia that does not respond to known treatments. Traced to a previously unknown coronavirus, the disease, which is fatal in about 10 percent of the cases, is termed SARS (severe acute respiratory syndrome). More than 8000 persons become ill between

February and July, of whom 813 die during that period.

Toxins from *Escherichia coli* bacteria, which cause some forms of diarrhea, are found to help protect against colon cancer.

Bandages that include the protein fibrogen, promoting clotting and causing bleeding to stop more rapidly, are developed by Gary L. Bowin and coworkers at Virginia Commonwealth University in Richmond.

Two studies show that bone marrow stem cells help rebuild damaged heart muscle when infused into a patient's heart.

American Paul Lauterbur of the University of Illinois in Urbana and Englishman Peter Mansfield [b. 1933] of the University of Nottingham share the Nobel Prize in physiology or medicine for advances in the development of nuclear magnetic resonance that led to magnetic resonance imaging (MRI). In a rare public dispute over a Nobel award, Raymond Damadian protests the prize in a series of newspaper advertisements claiming that his 1971 work originated MRI. *See also* 1973 PHY; 1971 MED.

✿ Physics

Takashi Nakano and a team at Osaka University in Japan announce that a search of data from 2001 reveals that their SPRing-8 synchrotron particle accelerator has produced the first examples of particles that contain five quarks — all previous hadrons contained either two or three quarks. The pentaquark, as the particle is termed, had been predicted in 1997 by Russian theoretical physicist Dmitri Diakonov and coworkers, who also spurred the search for the evidence that

pentaquarks had indeed been produced. *See also* 2002 PHY.

Two groups independently create the first molecular BEC. *See also* 1995 PHY.

Z. Farkas, G. Bartels, T. Unger, and D.E. Wolf calculate the motion of a disk that is rotating (on its flat side) while it moves across a flat surface — for example, a spun coin on a tabletop. The disk travels farther when spun, and both forward motion and spinning stop at exactly the same moment because of opposing frictional forces, which differ from those on a nonrotating disk.

Russian Alexei A. Abrikosov of the Argonne National Laboratory in Illinois, Vitaly L. Ginzburg, formerly with the P.N. Lebedev Physical Institute in Moscow, and British-American Anthony J. Leggett of the University of Illinois at Urbana share the Nobel Prize in physics, Abrikosov and Ginzburg for development of the theory explaining a type of superconductivity that persists in the presence of a magnetic field, and Leggett for the theory behind the superfluidity of liquid helium-3 based on ideas similar to those that explain some forms of superconductivity.

I Tools

Jason McKeever and H. Jeffrey Kimble of the California Institute of Technology in Pasadena (Caltech) and coworkers develop a laser that consists of a single atom of cesium that is trapped between two mirrors and cooled to near absolute zero. Prodded with an ordinary full-sized laser, the cesium atom emits highly coherent laser light for nearly a tenth of a second before escaping from the trap.

↗ Transportation

The space shuttle *Columbia*, which had been launched on January 16 carrying Michael Anderson, Kalpan Chawla, Laurel S. Clark, David Brown, Rick Husband, William McCool, and Ilan Ramon (the first Israeli in space) disintegrates during its approach to landing on February 1, killing all crew members. About 1 kg (2 lb) of insulation foam from the fuel tank had broken off during the launch and damaged the left wing, tearing a hole thought to have been 20 to 25 cm (8 to 10 in) across. On re-entry, the opening permits an extremely hot plasma generated by re-entry to pass into the wing where it melts aluminum struts. The wing eventually shears off, the automatic guidance system tries to compensate, and the immense heat and pressure of re-entry break the vehicle apart.

On January 1 China opens a commercial maglev connection between Shanghai and its airport. The line, 30 km (19 mi) long can carry passengers at 400 km (250 mi) per hour. The trip from start to finish takes just 7 minutes. *See also* 1997 TRAN.

On October 15 China successfully orbits its first satellite carrying a human. Yang Liwei successfully travels 14 times around Earth before landing in Inner Mongolia after 21 hours in space.

On April 10 Air France and British Airways announce that they will discontinue flights of the only operating supersonic jet passenger plane, the Concorde, by the end of the year. The last flight takes place on October 24.

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