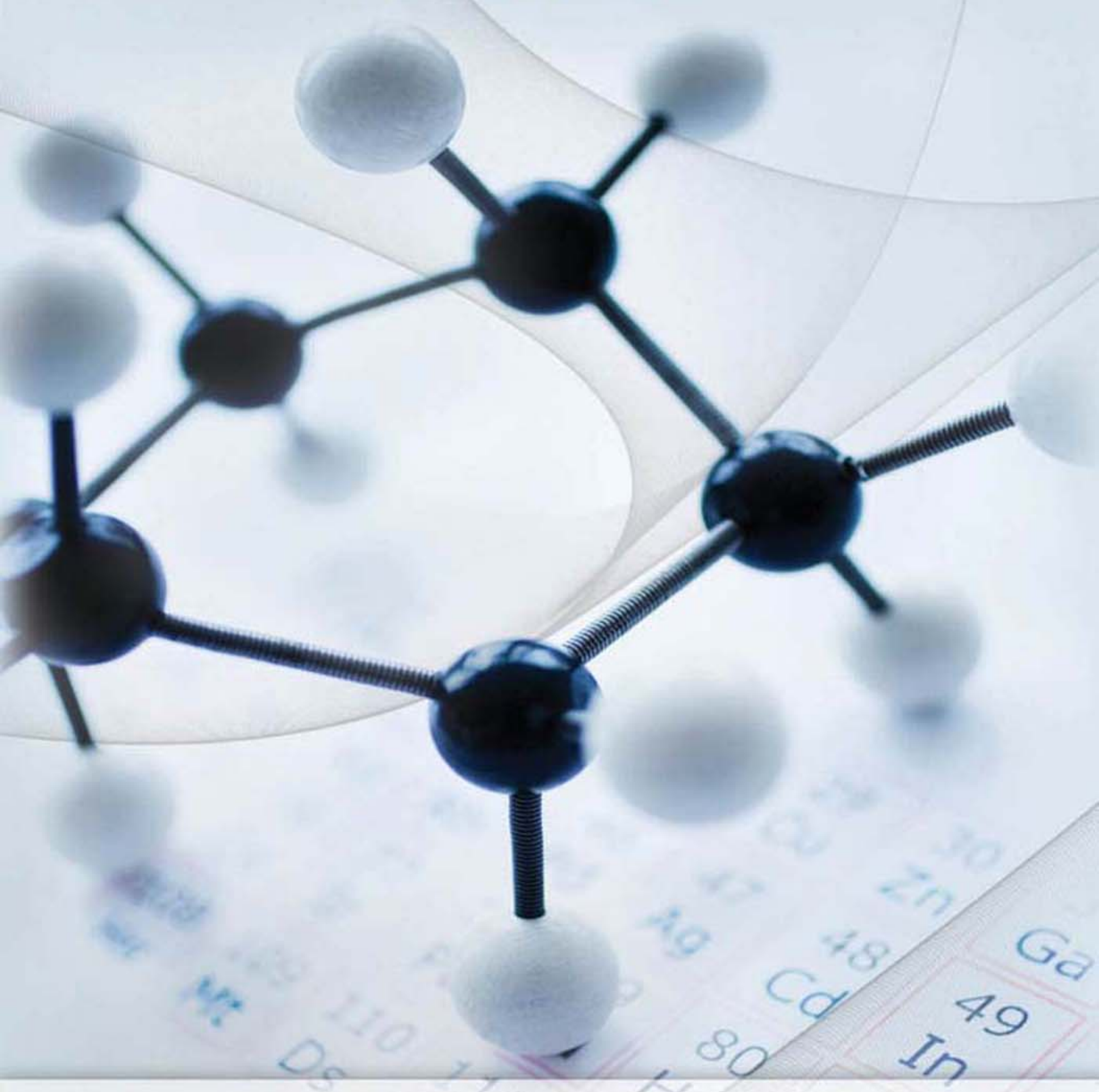
ROBERT E. KREBS



ENCYCLOPEDIA OF SCIENTIFIC PRINCIPLES, LAWS, AND THEORIES

Encyclopedia of Scientific Principles, Laws, and Theories

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Volume 1: A–K

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To Carolyn, who contributed much to this encyclopedia as my researcher, pre-editor, constructive critic, proofreader, supportive wife, and friend.

Preface

The development of universal scientific principles, fundamental physical laws, viable theories, and testable hypotheses has a long history. Humans are unique in that they can think about and contemplate the world around them, conceive ideas to explain natural events and processes, and then make use of what was learned. Early explanations of natural phenomena were interesting but not very reliable. Not until a few thousand years before the birth of Christ would recordings of history provide us with evidence of how humans related to the events and phenomena of nature. Some of the early Egyptian, Greek, Islamic, and Asian theories, as well as those from other cultures, demonstrated great insight into the structure and functions of animals, plants, matter, meteorology, agriculture, Earth, and astronomy. Our ancestors had the curiosity but lacked the means for forming truly accurate explanations and conclusions about nature as the understanding of cause and effect, and objective use of controlled experimentation was yet to be developed.

Included in this volume are a few ancient classical ideas and concepts that were theoretical *descriptions* of nature, often very inaccurate. This ancient "classical" philosophical process resulted in many dead ends. The modern sciences began when people learned how to *explain* nature by objectively observing events, asking questions that could be answered by making reliable measurements, using mathematics, and then considering probabilities to make reasonable predictions. This process led to "operational facts" that continued to be upgraded and corrected by the "self-correcting" nature of modern science. However, testing theories and hypotheses in a controlled situation developed late in human history and thus science, as we think of it, was slow to advance in ancient times. The development and implementation of scientific processes increased the "growth of knowledge," as well as the *rate* of growth of science from the seventeenth to the twenty-first centuries. During this period science accelerated at an astounding exponential pace, and this growth will most likely continue throughout the twenty-first century and beyond, particularly in the biological sciences based on quantum theory. None of our current understanding of the universe, nature, and ourselves would have been possible without men and women using the processes and procedures of scientific investigations.

The purpose of this encyclopedia is to present in two volumes a historical aspect for the important principles, laws, theories, hypotheses, and concepts that reflect this amazing progression of scientific descriptions and explanations of nature. Some more recent theories are also included. These scientific principles, laws, theories, etc., did not just appear out of "thin air." They are related to the period and people who developed these explanations and descriptions of the nature of our universe. The entries are listed alphabetically, in most cases, according to the name of the person credited with formulating the law, theory, or concept. Their names may be familiar to you. Others are less well known. Inventions and discoveries are included only if they contributed to the development or understanding of a particular scientific law, etc. Where appropriate, practical applications of particular laws and theories are included. Only laws, principles, theories, and concepts related to the basic sciences of physics, chemistry, biology, astronomy, geology, mathematics, and related fields such as medicine are included. Social, political, behavioral, and related studies are not included.

This encyclopedia is designed for the high school and college-level student as well as for the general reader who has an interest in science. Following the A–Z portion of the encyclopedia is a glossary of technical terms. The terms contained in the glossary are highlighted in **bold** type the first time the word is used in the text. Following the glossary are four appendices. Appendix A groups the encyclopedia entries by scientific discipline. Appendices B through D list Nobel Prize recipients for Chemistry, Physics, and Physiology/Medicine, respectively. Following the appendices is a selected bibliography containing sources for additional information related to the scientific principles, laws, theories, etc., included in the volumes. A general subject index concludes the set.

The following notations are used in this book:

BCE = Before the Common Era (instead of BC)
CE = The Common Era (Instead of AD)
c. = Approximate Date (e.g., approximate birth or death dates)
$\sim$ = Approximate amount, quantity, or figure
ppm = Parts per million
ppb = Parts per billion
% = Percent
α = Alpha particle (radiation)
β = Beta particle (radiation)
λ = Gamma radiation (similar to high-energy X-rays)

IMPORTANT:

Due to the technical nature of many of the original statements of principles, laws, theories, etc., and to the fact that some of the original statements are lost, are in a foreign language, or include "technical jargon," they have been paraphrased and restated to make them more comprehensible. The paraphrased statements of the principles or laws are printed in italics for easy identification.

About the Author

ROBERT E. KREBS has written seven books for Greenwood Press. He has taught chemistry, biology, and other sciences at several schools and universities. Dr. Krebs has served as a science specialist in the federal government and a research administrator in four universities. He retired as Associate Dean for Research in the Graduate College at the Medical Center of the University of Illinois at Chicago. He continues his lifelong pursuit of fostering scientific literacy through education.

Introduction

WHAT SCIENCE IS AND IS NOT

In his book *Asimov's Biographical Encyclopedia of Science and Technology* (1964) Isaac Asimov states "science is a complex skein, intricately interknotted across the artificial boundaries we draw only that we may the more easily encompass its parts in our mind. Pick up any thread of that skein and the whole structure will follow."

That "interknotted skein" may be thought of as a complex interrelationship between the *processes* and *products* of science. The processes are the *verbs* that relate to the so-called methods of science, whereas the products are the *nouns* that represent the knowledge about nature that we gain through the rational and pragmatic uses of scientific processes. Scientific research investigations of nature may lead to the technology/engineering that uses the knowledge gained through applying the processes of science. Thus, an understanding of Earth and universe requires the knowledge of science (the *products—nouns*) and the methods of obtaining that knowledge (the *processes—verbs*).

There are a series of analogies that can also be used to describe this process/product duality of science: basic science versus applied science, research and development, induction/deduction, and experimental investigation/technology innovations.

There is no *one* scientific method. Scientists do not use a cut-and-dried procedure during their investigations of nature. There are at least twelve characteristics and processes of science that make up the so-called scientific method, and in real-life, objective, rational scientific research one does not always start with number 1 and follow in order to number 12. First of all, scientists are skeptics when they investigate nature or hear about some extraordinary new discovery. As the saying goes "extraordinary claims require extraordinary evidence." They are skeptical of new evidence claimed by other scientists and will try to repeat their experiments. They also like to explore new problems, identify patterns or breaks in patterns existing in nature, and, in general, gather information and data to come up with answers to answerable questions and viable solutions to problems. In general, these processes are:

Observing—The "thread" used throughout a scientific investigation
Concentrating—Skepticism, critical thinking, induction/deduction
Recognizing—Scientific problems, questioning the ways things seem
Discriminating—Judging viability of identified problem, stereotyping
Relating—Old knowledge related to new information, being informed
Establishing—Cause and effect, eliminating irrational relationships
Formulating hypotheses—Asking answerable questions, forming answers
Testing—Selecting and using appropriate instruments and equipment
Experimenting—Objective testing, research using controls
Gathering, Treating, and Interpreting—Information and data
Using appropriate statistical instruments—Confirming and predicting
Communicating—Results and conclusions, peer review publishing.

A slightly different list of "techniques of inquiry" are given in Surendra Verma's excellent book *The Little Book of Scientific Principles Theories & Things* (2005):

1. *Observations* and search for data
2. *Hypothesis* to explain observations
3. *Experiments* to test hypotheses
4. *Formulation* of theory
5. *Experimental* confirmation of theory
6. *Mathematics* of empirical confirmation of theory
7. *Use* of this confirmation to form scientific law
8. *Use* of scientific law to predict behavior of nature.

It might be mentioned that these statements, and other similar ones, describe human ways of thinking and acting. The human concept of identifying and using the "processes" relates to a way of thinking and acting we call science. These rational procedures for acquiring new knowledge were developed and applied very late in human history. It is assumed that bits and pieces of these processes were known and used by proto-humans even before *Homo sapiens* arrived on Earth several millions of years ago. For example, as a means for survival early humans learned the difference between poisonous plants and "safe" plants to eat, and animals that humans could kill and eat and those more likely to kill and eat the humans. This required trial and error leading to stereotyping (profiling) varieties of plants and animals as well as other aspects of their environment pointing to ways of making practical use of something that "worked." These are rudimentary process of science. Applying the processes of observing, discriminating by stereotyping, relating new knowledge to what is known, and arriving at conclusions ensured humanity's continued existence, as well as the development of cultures and societies. This resulted in laws, civil and scientific, culminating in our modern use of knowledge gained through the use of the processes of science to sustain and improve human life.

Above all, scientists are critical thinkers and skeptics who do not accept many things and events at face value. They are not convinced just because others find something acceptable or convenient. They do not accept certainties just because others accept them, and they do not trust absolutes including absolute ideologies. Finally they have no "sacred cows," and they carefully select their authorities. They are aware that knowledge and science in general are subject to justifiable change and corrections.

Conversely, science is NOT many of the things often attributed to it.

First, science is not democratic—we do not vote on scientific theories or natural phenomena that scientists wish to explore. A possible exception might be when government "supports" a particular scientific effort.

Second, science is not based on everyone's opinion—some persons are more informed, wiser, better educated, and better equipped to explore natural phenomena or solutions to problems than are many other people.

Third, science is less subjective than other disciplines—although scientists are human and thus, to some degree subjective in their judgments, they are, as a group more objective in their outlook than most people. Claiming to be an authority does not make it so.

Fourth, science is not magic—much of science may seem like "magic" to the nonscientist, but there is no occult influence, sleight of hand, or conjuring related to the use of the processes that make up the scientific method. Pseudoscience and "junk" science are identified as such and exposed.

Fifth, science is not religion—scientists must have some degree of "faith" in the processes they use while conducting scientific investigations, but this is much different than the concept of having faith in spiritual nonexistent things. Although many scientists observe one form of irrational spiritual religious belief or another, to be successful in their particular discipline, they must separate theological ideologies from the rational science parts of their lives.

Sixth, science is not parapsychology—this includes nonsciences and the pseudosciences such as telepathy, clairvoyance, extra-sensory perception (ESP), psychokinesis, and unproven activities such as fortune-telling, tarot cards, reading bones and head bumps, witchcraft, channeling, astrology, etc. These types of activities are irrational and have no bases in facts gained from controlled experiments to verify them. It is said that about 75 percent of the people in the United States believe in angels; it is doubtful that many scientists do because no verifiable evidence of such entities exists.

Seventh, science is not politics—although politics sometimes attempts to dominate science for its own purposes, science is best kept out of the political environment except in the use of science in an advisory capacity to the political operatives. Conversely, politics is best kept out of scientific endeavors. This is difficult because governments of the developed world have increasingly provided funds to support scientific investigations, and many believe that control follows the money, or as the saying goes: He who pays the piper selects the tunes. Peer review panels have been established to ensure the scientific viability of proposed research sponsored by the government. Unfortunately, as with any system of controls there are a few flaws. Furthermore, political science is not a really a science but a study of politics. Just as economics is not a science but rather is more of an "art" that uses some of the processes of science, such as statistics, to study the economics of a society.

Eighth, science is not philosophy—historically there were philosopher/scientists and not much distinction was made until the eighteenth century "enlightenment period" of history when modern concepts of science as a systematic self-correcting process were developed. No other discipline or intellectual/social activity has a natural built-in self-correcting component.

SCIENTIFIC PHYSICAL LAWS

The concept of "laws" is as old as civilization and originally implied a "law giver" that was often interpreted as one type of god or another. The laws of science grew out of the early concept that the universe operated in certain ways and that "gods" established these particular laws that controlled nature. These several gods later evolved into a supreme lawgiving god who controlled nature according to his or her whims. This concept changed as humans became more curious and the "lawgiver" became the "worker of nature," which, in turn, became "natural laws." By the time of the Enlightenment, the concept became the "laws of science." This evolution of "scientific laws" naturally followed as humans learned how to objectively and logically examine and explain the workings of nature. It might be mentioned that while some so-called scientific theories were assigned the title "law" many years ago, many more modern theories, such as the theory of relativity, could just as well be referred to as the "law of relativity" today. Accepted and established *theories* are similar to accepted and established *laws* as far as authenticity is concerned. In other words, a scientific law is derived from a theory that has been proven and repeatedly verified by the application of mathematics and is consistent in predicting specific effects.

Scientific physical laws are statements of fact that explain nature and how it works and are not merely applicable to the nonliving things in the field of physics (matter and energy). Scientific laws also apply to all living things in the field of biology (plants and animals), and all areas of nature. Physical laws do not apply to things that are not natural, for example, the spiritual, philosophical, and parapsychological. Physical laws are generalized factual principles that describe how things behave in nature under a variety of circumstances. Where did these physical laws come from? The answer is obvious—from within the universe itself. We live in an ordered universe, made comprehensible by applying the concept of "rules" and using intelligent powers of reasoning, logic, and critical thinking. Scientific physical laws describe *how* things work and to some degree *what* they are in reality, but not always *why* they work as they do (e.g., gravity—we really do not know *what* gravity is or *why* it works as it does, but it is universal, predictable, and can be described mathematically). Scientific laws are consistent, long lasting, universal, and rational. In other words, a phenomenon, event, or action that occurs and behaves in the same manner under the same conditions, and is thus predictable, can be stated as a scientific law. These are sometimes referred to as "fundamental laws," "universal laws," "basic laws of science," or just "physical" or "scientific" laws.

At least five characteristics apply to all scientific laws: 1) They can be expressed mathematically. (Mathematics is basic to understanding nature and expressing scientific laws—even abstract mathematics.) 2) Physical laws are not always exact (as is mathematics). Scientific laws may need future "adjustments" as more knowledge is gained concerning the natural phenomenon as expressed by the law (but revisions are not made often nor extensive). 3) The natural systems may be complex and contain many "pieces," but the law describing the phenomenon always turns out to be simple. The universal "theory of everything" (TOE) or the "grand unification theory" (GUT) is expected to be an extremely complex composite of matter/energy. Even so, scientists predict that when found, the TOE or GUT will be a very simple mathematical expression. 4) Most important, scientific theories are universal. (Any well-established physical law that applies on Earth also applies throughout the universe.) And, 5) by using statistical probabilities, scientific theories can be used to predict future natural events in the real world.

SCIENTIFIC PRINCIPLES

Scientific principles are similar general statements about nature as are scientific laws. A scientific principle of nature must be objective and universal. Principles are not dependent on the views or statement of individuals but must be true from all points of view and true from all points of reference in the universe. There are only a few general, fundamental, and overriding postulates from which scientific laws and theories are derived. One of the unifying principles is *symmetry*. The scientific definition of symmetry relates to the orientation of something regardless of its orientation in space and time. No matter where in space or at what time in the past, present, or future the event occurs, acts, or reacts, it will do so in the same way. Symmetry also enables an object to rotate on a fixed axis in any orientation regardless of where in the universe it is located, and it will move at a uniform velocity in a straight line regardless of orientation. Symmetry in our everyday lives is considered twofold—bilateral and radial. Rotational symmetry of a sphere does not point to any specific direction in space. Anything that can be reoriented or its position changed while keeping its same basic geometry is considered to be symmetrical. An example is a two-dimensional square drawn on a piece of paper. Despite its orientation, it will look the same (unless you view it from the edge of a piece of paper). Some three-dimensional figures and objects when examined can exhibit two kinds of symmetry—bilateral and radial. For example, a drinking glass can be cut lengthwise (bilateral) or crosswise (radial). The human body is considered to have bilateral symmetry.

Another fundamental principle for all physical laws is *conservation*. The principle of conservation of matter and energy is related to symmetry because everything is in balance—somewhat like the reflection in a mirror or a process that obtains equilibrium. (Note: the fundamental concept of the conservation of energy is also known as the "first law of thermodynamics.") When something comes out the same way or results in the same answer, no matter what takes place during the event, conservation is involved. Another way to look at conservation is the principle (concept) of *cause* and *effect*. All effects (events) have a cause, or possibly several causes may be related to the effect, but there is a symmetrical pattern involved in this natural phenomenon. This is true for quantum mechanics that connects the "minimum principle" with the laws of conservation. There are antiparticles for all particles, and positives (+) for negatives (−). In other words, they are symmetrical but opposites and are conserved (no basic loss or gain). The fundamental property of mass is inertia. Inertia is the property of an object (with mass) that offers resistance to any change in its position or speed (orientation in space) when a force is applied to the mass. For our Earth and solar system this explanation is adequate, but inadequate for the relativity of space and time. Einstein's principle or theory of relativity redefined mass when considering the vastness of space, as expressed in his famous equation $E = mc^2$, which equates mass and energy as being conserved. (See Einstein for more on this principle.)

Humans did not invent the principles and laws of physics—they came from the formation of the universe from the big bang—from the void of the spontaneous formation of matter and energy—not a supreme being.

Other examples of conservation principles are Newton's three laws of motion and the theory of kinetic energy of particles that can be

It might be mentioned that our recent explorations of space by unmanned vehicles that ''fly'' by other planets and their moons would be impossible to perform accurately if it were not for the use of the theory of relativity in the mathematical calculation to guide the flight path. Without the use of mathematical constants, scientific principles, laws, and theories by NASA's space exploration program, astronauts would have had a more difficult time landing on the moon and would make the planned trip to the planet Mars more hazardous.

expressed in standard mathematical terms. A different example is the uncertainty principle related to quantum mechanics used to explain the nature of subatomic particles and energy. The uncertainty is based on the inability to ascertain, at the quantum level, the exact position of a subatomic particle, while at the same time trying to determine its momentum energy. The converse is also evident as a subatomic particle's momentum cannot be determined at the same time as locating its position. Treating the quanta data statistically solves this dilemma. Indeterminacy of quantum mechanics is a good example of the use of statistical probabilities to solve a problem (see Heisenberg).

Interestingly, it seems that there is a deep correlation or connection between the concepts of symmetry and the conservation laws. Someday there may be a common mathematical formula or constant that relates the two ideas.

SCIENTIFIC CONSTANTS

Generalized scientific principles involve mathematical rules. In other words, the answer reached will always be the same if the mathematical rules are followed. This concept utilizes what are known as fundamental *constants* that are mathematical expressions that establish a mathematical relationship between two or more variables that never change their values. These constants never change regardless of where or how they are used in the universe and assist scientists in the formation of mathematical expressions of universal scientific laws and theories. The preceding paragraph on Einstein's theory of relativity contained a constant that is universally accepted. It is the speed of light (the c which he squared) in the formula $E = mc^2$. The speed of light is 186,282 miles per second (299,792 km/sec) and applies only when light traverses unobstructed space. Other examples of the many constants used in mathematical expressions in science include Planck's constant ($\hbar$), and the elementary charge of an electron (e^-). (See gravity and Coulomb's law related to electrical charges over distance as examples.)

> There are over thirty fundamental physical constants that have specific and universal invariant quantities. These constants are expressed as symbols representing mathematical expressions that have a degree of accuracy as high as possible to obtain. Some examples of more familiar and frequently used fundamental physical constants and their mathematical expressions are:
>
> *Planck's constant* ($\hbar$) is $6.6260755 \times 10^{-32}$ Joules/second.
> *Elementary charge* (e^-) is $1.60217733 \times 10^{-19}$ Coulombs.
> *Avogadro's number* (N_A) is 6.0221367×10^{23} particles per mol.
> *Electron's mass* at rest (m_e) is $9.11093897 \times 10^{-31}$ kilograms.
> *Proton's mass* at rest (m_p) is $1.6726231 \times 10^{-27}$ kilograms.
> *Neutron's mass* as rest (m_n) is $1.6749286 \times 10^{-27}$ kilograms.
> *Atomic mass* unit (*amu*) is 1.66054×10^{-27} kilograms.
> *Bohr radius* (atomic) (*a0*) is 5.29177×10^{-11} meters.
> *Acceleration* due to gravity (g) is 9.80665 meters/sec^2.
> *Gas constant* (R) is $8.3145'$ m^2 $\times$ kg/s^2 $\times$ K $\times$ mol.

SCIENTIFIC THEORIES

The origin of the word "theory" is from the Greek word *theorein* or *theoria* that means "to look at" or to be "observed" as actors in a theater production are observed. In modern usage it does not mean that a person is seeing something not real or staged, or just as a guess or hunch.

Scientific theories are a type of model designed as general explanatory statements about the workings of nature. A theory might be thought of as a hypothesis that has been tested by experiments. At times it is possible for an exception to be found in a theory, but if this happens the exception is usually found and corrected or the theory is discarded. Theories can be used to predict natural phenomena and lead to more specific laws.

Many people think that a theory and hypothesis are somewhat interchangeable and can be related to a not well defined idea. In other words, a statement may be tested even though it may not be true. This confusion may result when the same scientific description of something appears to be in two different stages that are testing the idea. The hypothesis is a statement that is used in the early development of the research investigation of phenomena. The idea is new, and results have a good chance of being wrong, even though correct data to be analyzed is presented. An example is the theory that electromagnetic radiation (light) requires some form of matter, such as the aether, in space to transmit electromagnetic waves. If the data gathered from related investigations can verify the experiment consistently, then the concept may be considered a theory. Conversely, if further experiments arrive at different and more viable explanations for the phenomenon then the theory may be falsified, which is what happened to the theory of the aether.

Some modern scientists have other ways of looking at this conundrum by thinking about scientific "models" instead of theories or physical laws to describe the reality of nature. Some consider the term "theory" as handicapped with much social and historical baggage and believe that the concept of "model" can be much more productive as a statement for a well-established scientific idea or concept. Even so, the terms "hypotheses," "theories," "laws," and "models" are all important concepts of science; and, at some point, they all started as ideas. They all may be thought of steps in the systematic searches for "truth," which in science means the way things are—not as some humans would like them to be. Also, "truth" is not relative as some advocate. Accepted scientific theories are established facts and truths related to scientific laws and are viable and proven fundamental models (statements) about nature. Many established scientific theories might be considered laws because they both meet the same criteria for proven ideas.

Scientific models of nature are mathematical constructs of step-by-step rules that reflect what happens in actual natural events. Scientific models are often undated and are revised as new evidence become available. Scientific theories may therefore be thought of as types of models designed as general explanatory statements about the workings of nature. As established explanations of how things work in nature, they are the end points of scientifically gathered evidence about specific events that

In his book *The Trouble with Physics*, Lee Smolin (2006) explains why the recent "string theory" was proposed to combine all theories of matter and energy into one simple unified theory, but it has not yet become a proven theory for several reasons, mainly because it cannot, as currently stated, be used to make predictions. Smolin describes a theory as:

> "In science, for a theory to be believed, it must make a prediction—different from those made by previous theories—for an experiment not yet done. For the experiment to be meaningful, we must be able to get an answer that disagrees with that prediction. When this is the case, we say that a theory is falsifiable—vulnerable to being shown false. The theory also has to be confirmable, it must be possible to verify a new prediction that only this theory makes. Only when a theory has been tested and the results agree with the theory do we advance the statement to the rank of a true scientific theory."

may incorporate other laws and hypotheses. Humans derive all theories, and as such scientists make linguistic constructs of assumptions. They are similar to, but much more than, educated guesses because they are the results of crucial observations, experimentation, logical inferences, and creative thinking. They are not the same as what we think of as "guesses" as stated in everyday life. They are neither undocumented statements nor uninformed opinions. People often come up with "theories" based on social or behavioral notions or assumptions, which are often accepted by faith. These nonscientific "theories" are without experimental proof and seldom based on mathematics, verifiable facts, measurable data, and evidence. The main test of validity (truth or correctness) of an idea, concept, or theory (model) is found in the results of the experiment, and when possible, a controlled experiment. Theories advanced by scientists can be described as predictions based on the scientist's knowledge of a probable occurrence within a given set of circumstances or conditions. In fact, the validity of a theory, law, or model is determined by its predictability of one or more events. The nature of science is that exactly the same thing may *not always* occur at exactly the same time in exactly the same way in nature, but this does not negate the requirement of predictability of the law, theory, or model. Therefore, scientists, through experimentations, often seek a statistical average upon which to make their predictions. This being said, a proven fundamental scientific law or theory is as close as humans can get to 100 percent truth. Unfortunately, there are some people who consider everything relative (not in the Einstein concept of relativity as related to one's point of reference) but in accepting that everyone's relativity and often ambiguous "truths" are as authentic as proven scientific laws and theories.

An important characteristic of a theory is that it must be stated in such a way that it is nonambiguous. A vague theory cannot be proven wrong, and it is possible to come up with almost any answer desired for an ambiguously stated theory. Confirming a theory requires specific conditions, an experiment (controlled, if possible), and measured results that are analyzed statistically. If the related facts indicate a high probability for its validity and reliability, the theory can then be said to be justified and acceptable. Even so, there must exist the possibility that the theory may not be quite correct and will require additional testing, etc., and new knowledge related to the basic theory becomes available.

A theory is only as good as the limited number of assumptions and generalizations postulated. The fewer astute assumptions incorporated in a theory, the more likely it will stand the test of time. This is known as Ockham's razor (William of Ockham, c.1284–1349) which is a maxim that states that "*Entities ought not be multiplied, except from necessity*." In modern

> There are two general classifications of theories. One covers a large range of ideas and concepts, often referred to as "breadth" or "broad" theory. Historically, ancient people attempting to understand their world used "broad theory" such as myths by using stories and folktales to explain observed phenomena. Scientists are still attempting to reduce all scientific theories, principles, and laws into a unified field theory (UFT), grand unification theory (GUT), theory of everything (TOE), or come up with the "final answer." However, theories based on the laws of gravity, time, conservation, symmetry, relativity, quantum mechanics, etc., are not yet explained in ways that can be incorporated into a general, universal theory of everything. Nature is extremely complex, and humans are still attempting to understand it more fully.
>
> In summary, a theory must exhibit the following conditions: 1) It must explain the law from which it was derived; 2) It must in some way be related to the law it challenges; 3) It must be able to predict new, verifiable adjustments to the law or postulate a new law; and 4) it must be stated in such a manner that it can be proven false as well true (validity/true and reliable/repeatability).

vernacular it might be thought of as "KISS" (keep it simple stupid). In other words, the number of unnecessary assumptions should be avoided in formulating theories and hypotheses.

SCIENTIFIC HYPOTHESES

The word "hypothesis" comes from the Greek, *hypo thesis*, meaning "placed under" or "foundation." Somewhat similar to a theory a hypothesis is a more tentative observation of facts. Every scientific law and theory began as an idea, question, or hypothesis. Hypotheses and theories lend themselves to deductions that can be experimentally tested. A hypothesis is a logical and rational explanation of a series of critical observations that have not yet been disproved or proved, nor accepted by the scientific community. Hypotheses are reasonable statements, measurable assumptions, and generalizations drawn from a series of observations and selected facts. In other words, scientists confirm a hypothesis by experiments under controlled conditions, and if the data resulting from the experiments do not support the original hypothesis, it must be altered or discarded.

The origins of hypotheses (or concepts) are immaterial. They can be derived from intuitions, dreams, or as ideas arrived at by scientists who have knowledge and understanding of the subject related to the hypothesis. What matters is that the investigator must be familiar with the processes (methods) of scientific research and that the hypothesis is systematically tested to determine consequences. Like theories, hypotheses are products of the informed imaginations of scientists, but they are not wild speculations. Hypotheses are only accepted when tested and confirmed by additional observations by other investigators who conduct their own related experiments.

A viable scientific hypothesis must be stated in such a way that it has some chance of being disproved, and proved, and that it conforms to the observed facts (just as with a theory). Hypotheses can be "proved" or "disproved" by continuing observations of the phenomena and additional experimentation. It is the responsibility of the person advancing the hypothesis (or theory) to "prove" his or her case—not the responsibility of someone else to disprove it, although others can certainly challenge the results and conduct their own related experiments for another person's hypothesis. As an example, it is the responsibility of someone who states as a fact that angels, ghosts, and spirits exist to prove that they are real and actually exist. It is not the responsibility of science to disprove such beliefs (hypotheses).

Scientific hypotheses can only answer questions for which answers can be achieved by observing, testing, measuring, gathering data, and statistically treating and analyzing the data. The results become valid and reliable only when others repeat the experiment and obtain similar results. This is why science can deal only with "answerable questions." Most questions are not "answerable" in a scientific sense nor can they be stated as a scientific hypothesis because answers for such questions cannot be measured, or effectively analyzed. For example, the questions: "What is the secret of success?" or "How can I become more popular?" or "How can I become rich?" (One wag suggested that that person acquire more wealth.) These are, scientifically speaking, nonsense questions that don't lend themselves to rational answers. Even so these are the types of questions many people ask—the answers just cannot be gleaned by controlled experimentation and the analysis of data. For instance, "success" is subjective and not the same for everyone. "The" implies there is only one secret to success. And, if it is a "secret," no one knows the answer. Being able to formulate questions that can be answered by conducting controlled experiments by all who wish to investigate nature requires a statistical analysis of data. A scientific hypothesis (also theory, principle, or law) must be changed if new observed facts or experiments contradict or even slightly alter the original statement or data. This self-correcting process is one of the basic reasons that science may some day triumph over ignorance.

SCIENCE CONCEPTS

A concept is one step above a *specific idea*. Related to ideas are assumptions (notions) that are based on beliefs in or about something, most often accepted without proof. What counts in science is how ideas are developed into viable concepts, hypotheses, theories, and models that accurately describe nature. Most ideas and concepts people come up with are a "dime a dozen" and seldom result in anything beneficial.

CAUSALITY

There is one more concept that can be confusing. It deals with the causes of events on the micro/quanta and macro/universal levels. Causal laws are considered those that can predict and explain empirical and theoretical laws that describe the nature of our known universe. This relationship is usually referred to as "cause and effect." Some science philosophers classify causal principles as 1) empirical generalizations from facts based on other facts, 2) a rational interpretation of a required connection between two or more events, and, 3) a cause may be a useful or pragmatic explanation of science. This is what we usually consider as a specific cause (or causes) leading to a specific effect (or effects or events) but may not necessarily be a direct observable connection between the two.

During Sir Isaac Newton's time science was considered a system to describe a mechanistic, deterministic, and reductionist world. Determinism and predictability are not the same. Determinism deals with how nature behaves, particularly nature as we know it within the solar system—it depends on the "laws of nature." Predictability is based on what scientists are able to observe, measure, and analyze, as related to outcomes for specific events. To better understand complex nature, scientists attempt to "reduce" its complexity to more manageable and understandable laws, principles, and theories. We live our everyday lives in a Newtonian mechanistic solar system based on logic, physics, and mathematics, whereas the Einsteinian universe is based on theories of relative space and time in particular perspectives to each other that are not easy to apply on Earth as are Newtonian laws of physics. Why? Because the setting for events on Earth is very small compared to the relational aspects for the frames of reference in space and time of the universe. Einstein's relativistic physics rendered some of Newton's laws of motion only approximations. Newton's laws do not hold up when considered for the immense universe consisting of great space, energies, masses, and velocities in different frames of reference over very great distances of space and time.

Historically, all effects or events were assumed to have a cause, or possibly several causes, or to be co-events. We now know that many natural events are described and predicted by statistical probabilities, not mathematical certainties. This is true for very large events in the universe and the very small events as related to subatomic particles and energy. These very small events led to quantum theory and indeterminacy (uncertainty principle) resulting in some problems with the cause-and-effect concept for accepted physical laws. This is one reason scientists think in "statistical probabilities" rather than what is "possible." Probabilities involve measurements to arrive at predictable events, whereas possibilities may or may not lead to an event.

No one ever expects an *effect* to precede a *cause*. Scientists would say that such a situation is unlikely (with a very low degree of probability), but we never know for sure. In other words, the probability of the effect preceding the cause is practically zero. There are some effects (events) in nature where the cause or causes have not been detected and thus not well understood. This is one reason that the cause-and-effect relationship is not highly thought of by some scientists.

The nature of the universe is extremely complex. The universe is about 13 to 14 billion years old, the Earth is about 3.5 to 4 billion years old, and thinking, rational humans have been on Earth for only several hundred thousands of years. Early humans must surely have wondered about the world around them and by observing cycles of nature speculated how things worked and affected them. It has been about five hundred years since humans arrived at a systematic method of "asking" questions of nature for which rational answers were possible. There are many areas of nature that we do not yet understand, including our own nature and role in the scheme of things. No doubt, we will continue exploring the unknown throughout the twenty-first century and beyond.

A

ABBE'S THEORY FOR CORRECTING LENS DISTORTIONS: Physics: *Ernst Abbe* (1840–1905), Germany.

The equation for Abbe's theory is: u'/sin U' = u/sin U, where u and u' are the angles for the entering and exiting of rays from the object to the image, as in a microscope.

Ernst Abbe was raised in a poor German family but managed to become a physics professor at the University of Jena (now located in Germany). He also was the director of the university's observatory and a theoretical optical consultant for the Carl Zeiss instrument company. Up to this time the field of optics was an "art," but Abbe brought several viable theories of optics to bear on several problems of the day, for example, chromatic aberrations in lenses. He also worked with Otto Schott, a glassmaker, to improve several optical devices. In 1888 he became the owner of the Carl Zeiss optical company that is known worldwide for its high-quality precision instruments.

The *Abbe sine condition* is a mathematical concept used to make lenses that produce sharper images and less distortion. It is a means to eliminate spherical aberration of an optical system to produce an **aplanatic lens** (corrected lens). In 1886 Abbe used his mathematical approach to develop apochromatic lenses (corrected for chromatic and spherical aberrations) to eliminate primary and secondary color distortions. The *U* and *U'* are the corresponding angles of any other rays transmitted.

Abbe's contributions to the field of optics include several inventions, most notably the Abbe condensing lens to focus light onto microscopic slides, the achromatic lens, the Abbe refractometer, and the prismatic binocular, a design for binoculars that is still used today. His contributions led to the improvement of all of optical instruments, including sharper images with less color distortion for cameras, microscopes, refracting telescopes, spectroscopes, and so forth.

See also Newton

ABEGG'S RULE AND VALENCE THEORY: Chemistry: *Richard Abegg* (1869–1910), Poland.

Chemical reactions are the result of electron transfer from one atom to another.

Richard Abegg attended several universities in Poland and Germany, graduating from the University of Berlin in 1891. He was the pupil of Wilhelm Hofmann, the famous theoretical chemist. Although trained in organic chemistry, Abegg was interested in the physical nature of chemistry. He was working as an electrochemist when he published his famous paper, "Die Elektronaffinität," that explained his theory on the combining power of chemicals (**valence**).

Abegg not only became famous for what became known as the *Abegg Rule*, but also he arrived at his rule years before the existence of valence for elements was firmly established. His rule and valence theory predated Dmitri Mendeleev's development of the periodicity of elements. The rule stated that each element has a positive valence and a negative valence whose sum is eight. This predated the "octet rule" for the periodic table. He further theorized that the *attraction of electrons for atoms of all elements has two distinct types of similarities or valences, that is, a "normal affinity" (valence) and a "counter affinity" (countervalence).*

His theory that two related valences always add up to eight, published in 1869, is responsible for the octet rule as related to the **Periodic Table of Chemical Elements** (*see* Figure S2 under Sidgwick). Abegg's early theories of valence became valuable for later chemists and were used to explain chemical reactions and the organization of the periodic table. For instance, elements in the groups with just one or two electrons in their outer orbit (metals), when combining with other elements (nonmetals), tend to give up their outer electron(s) and thus attain an outer octet of electrons. Elements with six or seven electrons in their outer orbits tend to acquire electrons to complete their outer octet orbit.

The octet rule is just a device to remember the position of some elements in the periodic table, and it is only valid for elements located in the higher periods and groups of the periodic table. The concept of valence has become extremely useful in all fields of chemistry.

See also Mendeleev; Newlands; Sidgwick

ABEL'S THEORY OF GROUPS (ABELIAN GROUPS): Mathematics: *Niels Henrik Abel* (1802–1829), Norway.

Following is a list of Niels Abel's notable accomplishments in his short lifetime:

1. In 1824 at age nineteen he proved that there was no general algebraic solution (proof) for roots to solve *quintic equations* by radicals, or in other *polynomial equations* of degrees greater than four.
2. In 1826 he published an updated version of this proof in August Leopold Crelle's new journal on mathematics.
3. He invented a branch of mathematics known as *group theory*, for which he has become famous.
4. He did original research in the theory of functions including *elliptic* and *hyperelliptic functions* that later became known as the famous abelian functions.
5. He is also known for the *abelian group*, *abelian category*, *abelian variety*, and the *abel transformation*. Note: these terms are so common in mathematics that they

are expressed with the lower case (a). This is contrary to what one might expect when naming such important mathematical concepts and theories for a person who has received many of the highest honors in his field.

Niels Henrik Abel's story is that of a twenty-six-year-old genius's life of "rags-to-rags." He was born into a large family with six male siblings whose father was a poor Protestant minister in a church in Christiansand, a diocese in Norway. At age fifteen Niels proved to have a remarkable knack for understanding complicated mathematical principles. He was only age eighteen when the breadwinner of the family died, leaving the family to live in miserable conditions. A small government pension provided Niels an opportunity to attend the local cathedral school in Christiania in 1821. In 1825 he was awarded another state scholarship that enabled him to visit France for ten months where he became friends with many mathematicians. He briefly visited Germany where he met local mathematicians. As he was unable to secure a paying job, he ran out of money and had to return to Norway. Even after mastering a number of remarkable developments in the field of mathematics that few other mathematicians understood, Niels remained in a life of poverty as he sought, through the assistance of a friend, a position at the University of Berlin. The letter appointing him to this position by his friend, the amateur mathematician August Crelle, to whose journal Abel contributed several publications, arrived two days after his early death from tuberculosis on April 6, 1829.

The Abel Prize was established in 2001 by the King of Norway on the bicentennial of the birth of Niels Henrik Abel. This prize is awarded annually to an outstanding mathematician and is intended to stimulate interest in mathematics among young scientists and increase the amount of research in the field of mathematics, as well as improve the image of Norway as a nation of "learning." The Abel Prize in mathematics is considered on a par with the Swedish Nobel Prize in other fields.

Abel's theorem is proof of a fundamental theorem on transcendental functions. Abel's theorem, and his outstanding theory of elliptical functions, kept mathematicians busy for the latter part of the nineteenth century.

The usefulness of the Abelian group concept in mathematics is based on notations and is sometimes called the "commutative group" that can be additive or multiplicative. For example: if the group is (G *) a * b = b * a, the end product is immaterial. Complete discussion of the Abelian group theory is beyond the scope of this book.

ADAMS' CONCEPT OF HYDROGENATION: Organic chemistry: *Roger Adams* (1889–1971), United States.

1. *Additional hydrogenation will take place when hydrogen is added to double bonds of unsaturated molecules of organic substances such as liquid fats and oils.*
2. *Hydrogenolysis hydrogenation will take place when hydrogen breaks the bonds of organic molecules, permitting a reaction of hydrogen with the molecular fragments.*

The first type of hydrogenation led to the formation of solid or semisolid fats from liquid oils, and the second process is used in hydrocracking petroleum or adding hydrogen to coal molecules to increase its heat output. In the early 1900s Roger Adams' ideas resulted in the successful hydrogenation of unsaturated organic compounds by catalyzing them with finely powdered platinum and palladium metals under heat. It is similar to the process of reduction in organic chemistry that led to the hydrogenation of many of our fuels and foods, where liquid oils are converted to semisolid oils or fats.

The hydrogenation of unsaturated organic compounds is used in industrial processes that result in many of today's most popular products. Some examples are the synthesis of liquid fuels; the production of several alcohols, including methanol; the production of aldehydes and benzene derivatives; the synthesis of nylon; the hydrogenation process of peanut butter to make a smooth spread without the separation of the peanut oil; and hydrogenation of liquid vegetable oils to form margarine. Hydrogenation is also used to form solid petroleum fuels and some semisolid medications. The second type of hydrogenation led to an increase in the production of petroleum products from crude oil, such as gasoline.

ADHEMAR'S ICE AGE THEORY: Astronomy: *Joseph Alphonse Adhemar* (1797–1862), France.

> *Because Earth tilts 23.5% from its ecliptic (the orbital plane of Earth around the sun), the Southern Hemisphere receives about two hundred fewer hours of sunlight per year. Therefore, more ice accumulates on Antarctica than at the North Pole.*

In 1842, Joseph Adhemar proposed his theory, the first to provide a reasonable answer to the questions as to the causes of the ice ages. His theory is based on evidence gained from astronomical events expressed in his book *Les Revolutions da la mer* published in 1842. He was the first to propose that natural astronomical occurrences might be responsible for the ice ages and, by implication, global warming/cooling cycles. He realized that Earth is just one focal point in its elliptical orbit around the sun, which means that Earth is farther away from the sun in July. In addition, Earth's axis does not always point in the same direction in space; rather, it slowly rotates in a small circular orbit approximately every twenty-six thousand years (called *precession*). These astronomical factors, plus the inclination of Earth, cause the winters to be slightly longer for the Southern Hemisphere.

Due to the tilt of Earth on its axis the South Pole receives about 170 to 200 fewer hours of sunlight than does the North Pole. Adhemar claimed these differences were adequate explanations for the extensive ice build-up at the South Pole. It might be mentioned that during the current global warming trend, unlike the North Pole, the South Pole is still building up its ice sheet, which Adhemar claimed contributed to the ice age. However, many scientists today do not completely agree with his theory.

See also Agassiz; Kepler

AGASSIZ'S GEOLOGICAL THEORIES: Geology: *Jean Louis Rodolphe Agassiz* (1807–1873), Switzerland.

Agassiz's glacier theory: *The movement of glaciers created scratch marks in rocks, smoothed over vast areas of the terrain, gouged out great valleys, carried large boulders over long distances, and left piles of dirt, soil, and debris called moraines.*

In 1836–1837 Jean Agassiz arrived at the new idea that glaciers in his native Switzerland were not static when he realized that a hut on a glacier had moved over a period of years. He then constructed a line across a glacier and noted that after a year it had moved. After discovering rocks and scars in the landscape that he found under the glacier, he concluded that much of Northern Europe had at one time been covered with ice. This led to his theory of the cause and effect of glaciers. As a keen observer of geological phenomena he believed there was evidence of glaciers where none now exists. After his theory was published in 1840, he was invited to the United States in 1846 as a lecturer where he speculated that North America had also experienced the effects of glaciers. He further speculated that ice sheets and glaciers formed at the same time in most of the continents.

Agassiz's second glacier theory: *Glacier ice sheets had movements that included advancements as well as periods of retreat, which correspond to the ice ages.*

Jean Agassiz's work led to the concept that glaciers were the result of the ice age. As the ice sheets that covered Earth melted in the warmer zones, great deposits of compact ice were deposited in the colder regions of the Northern and Southern Hemispheres. These ice masses, now called *glaciers*, moved slowly toward the warmer areas, and they continue to move even today. Periodic ice ages, some much smaller than the original frozen Earth period, formed, advanced, and retreated over many millions of years. Ice ages on Earth are considered normal cyclic occurrences. Previous to Agassiz's glacier theories, scientists assumed glaciers were caused by icebergs. In fact, the opposite is true, icebergs are caused by the calving of huge chunks off the edges of glaciers that extend into lakes and oceans. Agassiz, sometimes known as the father of glaciology, also made contributions to evolutionary development through his study and classification of the fossils of freshwater fish.

Agassiz's theory of fossils and evolution: *The lowest forms of organisms were found in rock strata located at the lowest levels of rock formations.*

Before Agassiz devised his theory, William Smith (1769–1839), the English surveyor and "amateur" geologist, proposed that fossils found in older layers of sedimentary rocks were much older than the more modern-appearing fossils located in sediments laid down in more recent geological times. This concept answered some of the questions about the evolution of species because the ages of fossil plants and animals now could be determined by their placement in the rock strata. This information led to Agassiz's more formal theory on the subject.

Agassiz at first did not believe in evolution but later did accept the concept of evolution while still rejecting Darwin's theory of natural selection because it required long, gradual periods of change. Oddly, Agassiz's studies of fossils were used to support Darwin's theory of natural selection. Agassiz accepted and expanded on Georges Cuvier's catastrophism theory of evolution, which postulated periods of rapid environmental changes, not natural selection, as the basis of evolution.

William Smith was born in 1769 on a small farm and received little formal education. His interest was in collecting and studying fossils while he learned geometry. By age eighteen he worked as an assistant to the master surveyor, Edward Webb. This enabled him to travel extensively in England and led to his supervision of the digging of the Somerset Canal in southern England. The digging of the canal provided Smith with an opportunity to observe the fossils found in the sedimentary rock. He noticed that older-appearing fossils were always found in the older, deeper layer of rocks. This led to the principle that "The layers of sedimentary rocks in any given location contain fossils in a definite sequence." In other words, the same sequence can be found in different geographic locations, thus providing a correlation between locations. Smith's career expanded, and he became a well-known engineer who developed a complete geological map of England and Wales. He had difficulty in raising funds to publish his map, but it was finally published in 1815. A biography of William Smith by Simon Winchester titled *The Map That Changed The World—The Birth of Modern Geology* was published in 2001 by HarperCollins. The book's cover is a unique expandable geological map of the below-surface geological structure of Great Britain.

More recent uses of Agassiz's theories of ice ages and stratification of fossils should give pause to many claims that modern society is responsible for global warming and an increase in the extinction of plants and animal. Both processes have been occurring over eons of time as cycles in the cooling and heating of Earth and the rate of plant and animal extinction due to natural environmental changes. Although humans certainly influence and alter their environment, just as do all living organisms, which in turn result in some evolutionary changes, there are multiple causes and influences on these two interrelated natural cycles. These cycles most likely will continue long after the human species is extinct.

See also Adhemar; Agricola; Charpentier; Cuvier; Darwin; Eldredge–Gould; Gould; Lyell; Raup

AGRICOLA'S THEORIES OF EARTHQUAKES AND VOLCANOES: Geology (Mineralogy, Metallurgy): *Georgius Agricola* (1494–1555), Germany.

Agricola's original name was Georg Bauer, but he followed the custom of the time and chose the Latin name, Georgius Agricola. *Agricola* means "farmer" while his original name meant "peasant." In the 1540s Agricola's studies based on his observations of minerals and stratified layers of rock led to several geological theories.

Agricola's theory of stratification: *Stratified forms of rocks are the arrangement and relationships of different layers of sedimentary rocks as formed during earthquakes, floods, and volcanoes.*

The planes between different strata (layers) assist in determining not only the source of the sedimentary rocks but also the area's local history. In addition, the fossil content found in different strata provides a record of the biological and geological history of Earth. Today, the study of stratification is called *stratigraphy*, which is the branch of geology that studies the different layers of rock. Agricola's stratification system, though primitive, proved useful as one means of identifying the location and sources of petroleum.

Agricola's theory of earthquakes and volcanoes: *Earthquakes and volcanoes are caused by subterranean (below ground level) gases and vapors originating deep in Earth, where they are heated and then escape to the surface.*

A keen observer and practicing physician specializing in miners' diseases, Agricola's main interest was minerals, known in those days as metals. In 1546 he was one of the first to classify minerals according to their physical properties, such as color, weight, and texture. He believed these minerals/metals originated deep in the underground and were brought to the surface by earthquakes and volcanoes. Agricola was also known as a paleontologist for his

Although later scientists disputed some of his ideas and subsequently revised his theories, Agricola's publications were used in the field of geology for over two hundred years. His most famous book *De re metallica* (1556) provided much new information on mining and metallurgy, including mine management, how to use windmill-driven pumps, and how to derive power from water wheels. He updated the process required for working with metals. Much of the information in his writings, as was other knowledge of the Middle Ages, was derived from antiquity and Arabic scholars. Interestingly, in 1912 President H. Hoover and his wife Lou translated Agricola's book into English. It is still available. In 1546 Agricola published *De ortu et causis subterraneorum* (Origins and Causes of Subterranean Things) in which he updated the concept of "rock juices" as subterranean fluids. Also in 1546 he published, *De natura fossilium*, which was a new classification system of minerals (called fossils in those days) that was based on a mineral's physical properties such as color, weight, texture, solubility, combustibility, etc.

work with objects found in the soil, including fossils, gemstones, and even gallstones. He is sometimes referred to as the father or founder of mineralogy and the science of geology because he was among the first to describe fossils as once-living organisms.

AIRY'S CONCEPTS OF GEOLOGIC EQUILIBRIUM: Geology and Astronomy: *Sir George Biddell Airy* (1801–1892), England.

Airy, along with other scientists, proposed two theories of equilibrium as expressed in geological structures.

Airy's first theory of geologic equilibrium: *Mountains must have root structures of a lower density in proportion to their heights in order to maintain their isostasy (equilibrium).*

Isostasy is Airy's theory that there is a proportional balance between the height of mountains as compared to the distribution of the root structure or mass underneath the mountain. He claimed this equilibrium resulted in a balance of **hydrostatic** pressure for the formation of mountains. It became an important concept in geology and aided in the exploration of minerals and gas and oil deposits. Although his theory has been revised, it was a step in the right direction in understanding the dynamics involved in geological systems.

Shortly after graduation from Cambridge University in 1819 he wrote several successful textbooks in mathematics and optics. He later became a professor of astronomy and the director of the Cambridge Observatory where he developed several innovative instruments. These include a type of altazimuth device for lunar observations, a transit circle, and a new equatorial telescope with a spectroscope. He also devised an optical device with a central hole (called the *Airy disk*) to examine diffraction patterns of a point source of light.

His second theory deals with internal water waves and is based on ideas expressed by Vagn Walfrid Ekman (1874–1954).

Airy's second theory of equilibrium: *In areas where the sea is covered with a thin layer of freshwater, energy is generated by internal waves and is radiated away from ships, which subsequently produces a drag on ships.*

Because this slows the ship's progress, it is known as *dead water*. One area where freshwater and seawater are at different levels, which causes these internal waves to drag on ships, is the entrance to the Mediterranean Sea at Gibraltar.

A story from World War II pertains to the fact that the water in the Mediterranean Sea has a higher salt content due to evaporation than does the water in the Atlantic Ocean. Because the Mediterranean's water is saltier and thus denser, it flows out past the Strait of Gibraltar near the bottom of the Strait into the Atlantic Ocean. At the same time, the less salty (less dense) Atlantic Ocean water flows into the Mediterranean near the surface. It was suggested that when submarines wished to avoid detection as they passed through the fortified Strait of Gibraltar they drifted quietly in the less dense water into the Mediterranean near the surface. When submarines wished to leave without being detected, they drifted quietly in the more dense water near the bottom as they were "carried" past the protected Gibraltar and into the Atlantic. By using the difference in density of saltwater in the Atlantic Ocean and the Mediterranean Sea submarines could apply the "Airy waves" concept to their advantage. The success of this tactic remains unknown.

AL-BATTANI'S THEORIES: Astronomy: *Abu Abdullah Al-Battani* (c.858–929), Mesopotamia (present-day Iraq).

Abu Abdullah Al-Battani developed various theories after improving measurements completed by Ptolemy of Alexandria.

Al-Battani's theory of solar perigee: *Solar perigee equations demonstrate slow variations over time.*

Al-Battani determined that the sun's perigee (the point at which the sun is closest to Earth in Earth's elliptical path around the sun) is greater than Ptolemy's measurement by a difference of over 16°47′. Although Al-Battani admired Ptolemy, he improved on several of Ptolemy's calculations, including the ecliptic of Earth's orbit to its equatorial plane.

Al-Battani's theory of the Earth's ecliptic: *The inclination of the angle of Earth's equatorial plane to its orbital plane is 23°35′.*

This figure is very close to the current measurement. The ecliptic for Earth can also be thought of as the apparent yearly path of the sun as Earth revolves around it. In other words, it is the angle of tilt of Earth to its solar orbital plane that is the major cause of our four seasons—not how close Earth is to the sun. The Northern Hemisphere is tilted more toward the sun during the summer, thus receiving more direct sunlight for more daylight hours than in the winter, when the Northern Hemisphere is tilted away from the sun. The situation is reversed for the Southern Hemisphere.

Al-Battani's theory of the length of the year: *The solar year is 365 days, 5 hours, and 24 seconds.*

Al-Battani's calculations are very close to the actual figure of 365.24220 days that is accepted today. This led to more exact recalculations for the dates of the spring and fall **equinoxes**. The dates for the equinoxes and the accuracy for the length of the year were important for various religions of the world that base many of their holy days on the seasons and these particular dates.

Al-Battani's concept of the motion of the moon: *It is possible to determine the acceleration of the motion of the Moon by measuring the lunar and solar eclipses.*

Al-Battani was able to time the lunar and solar eclipses and thus able to extrapolate this figure to calculate the speed of the moon in its orbit. He also devised a theory for determining the visibility of the new moon. Albategnius, an eighty-mile plane surface area on Earth's moon surrounded by high mountains, is named for Al-Battani.

Al-Battani's concepts of two trigonometric ratios: 1) *Sines* (which he formulated) *were demonstrated as more practical and superior to the use of Greek chords.* (A chord is a line segment that intersects a curve only at the end of the curve.) 2) *Cotangents are the reciprocal of tangents.*

Considering the period in history during which Al-Battaini lived, his contributions to astronomy and mathematics are extremely innovative and accurate. Al-Battani devised tables for the use of *sines*, *cosines*, *tangents*, and *cotangents*, which are invaluable for modern algebra and trigonometry. Copernicus credited Al-Battani with advancing astronomy based on his work in trigonometry and algebra. For many years, Al-Battani's contributions to science and mathematics were considered preeminent and advanced the cause of knowledge over the next several centuries. He is sometimes referred to by his Latin name, *Albategnius*.

ALVAREZ'S HYPOTHESES OF SUBATOMIC COLLISIONS: Physics: *Luis Walter Alvarez* (1911–1988); United States. Luis Walter Alvarez was awarded the 1968 Nobel Prize in Physics.

Alvarez K-capture hypothesis: *The vacant inner K shell will capture an orbital electron as the electron moves from an outer shell to the innermost K shell of the atom.*

Luis Alvarez's discovery of the number of high-energy nuclear collisions of subatomic particles was the result of his developing a liquid-hydrogen bubble chamber. This "bubble chamber" was able to detect the decay of nuclei of atoms using the procedure known as K-capture of the orbiting electrons from the innermost orbit (K shell or orbit) of atoms.

He also worked on the World War II Manhattan Project where he developed the device for detonating the atomic bomb. In addition, he held over thirty patents, including those for unique radar systems. His large, seventy-two-inch bubble chamber first used in 1959 contributed to the discovery of many elementary subatomic particles.

Along with his son, Walter Alvarez (1940–), and several other geologists, he arrived at what is known as "the Alvarez asteroid impact theory" in 1980. The theory states that an asteroid about ten miles in diameter struck Earth approximately sixty-five million years ago with an impact that sent debris into the atmosphere that blocked the sun and caused worldwide storms, acid rain, and other chemical changes in Earth's air. Other conditions, such as fires and high winds, along with the many volcanoes present at that time, contributed to the disruption in the balance of the environment resulting in a cooling period during which much of the plant life was wiped out. This loss of plant life killed off the herbivores (animals that survive on plants) and subsequently the carnivores (meat eaters) that needed the herbivores as a food source. Thus, with their food supplies eradicated, all species of dinosaurs suffered extinction, that is the herbivores, carnivores, and omnivores.

> There is considerable evidence for this catastrophic event. A 120-mile-wide crater, known as the ''Chicxulub'' impact crater is located at the tip of the Yucatan Peninsula in the Gulf of Mexico. There is evidence that this impact caused huge tsunamis in the area. (It might be mentioned that another huge asteroid hit Earth at about the same time in the Arabian Sea off the coast of Bombay, India. It is called the *Shiva Crater* after the Hindu god of destruction and renewal.)
>
> Additional evidence for the Chicxulub Crater is known as the K-T layer of sedimentary deposits. This is a strip of clay with a relatively high concentration of iridium brought to Earth by the asteroid. (Note: the ''K'' stands for *Kreide,* which is German for ''cretaceous,'' and the ''T'' stands for ''tertiary,'' that are the two geological periods between which the clay strip of sediment is found.) Other evidences of the ancient event are the discovery of several rare earth elements (siderophiles), particularly the rare earth iridium, as well as tektites that are also found in the region. Tektites are quartz grains that were vaporized by extreme heat and pressure that crystallize into glass beads when cooled. Tektites result from high-impact meteorites, asteroids, and **bolides**. Many tektites are found in the K-T layer. Other evidence of the impact are layers of quartz and glass beads found at the crater sites.

AMBARTSUMIAN'S THEORY OF STELLAR ASSOCIATIONS: Astronomy: *Viktor Amazaspovich Ambartsumian (also known as Ambarzsumian Ambarzumyan)* (1908–1996), Armenia-Russia.

Star systems, including galaxies, form cluster type associations as they evolve.

Ambartsumian was a professor of astrophysics at the University of Leningrad and later at the University at Yerevan in Armenia. He established the Byurakan Astronomical Observatory in 1946 when he did most of his work in the evolution of galaxies and star clusters. His main interest was the **cosmogony** of stars and galaxies and nebulas.

His work on stellar dynamics led to his theory of stellar associations that is based on loose groups of young hot stars that are located near the disk-shaped plane of our Milky Way galaxy. This association occurs only with young stars that are just a few million years old. As they age over many millions of years, the galaxy's gravity will separate them from their relatively close association sending them further apart from each other. This seems to be evidence that new star formation in our galaxy is ongoing.

Ambartsumian was the first to propose that the T Tauri type stars are very young and are found in groupings (clusters) that are expanding. In addition, he demonstrated that as galaxies evolve, they lose mass. During his long career he also explored the nature of interstellar matter and the radio signals emitted by galaxies.

A small planet was recently named for Ambartsumian, as was a dwarf galaxy located in the constellation Ursa Major, referred to as *Ambartsumain's Knot*.

AMDAHL'S LAW: Computer Science: *Gene Myron Amdahl* (1922–), United States.

Amdahl's law of parallel computing can be stated in several ways, but it is basically a law related to the acceleration of computers from using just a single computer to multiple parallel computers. The law is used to find the maximum expected improvement to an entire system when only one part of the system is known. A simple statement of the law is: *Parallel computing that performs speedup of a parallel algorithm is limited by the fraction of the problem that must be performed sequentially, which is to say that a design is only as strong as its weakest link*.

In essence, this means it is not the number of computers involved that is the limiting factor, but rather it is the algorithm that cannot speedup beyond limits of the paralleling. The term "speedup" is defined as the time it takes a computer program to execute a program with just one processor, divided by the time it takes to execute the program in parallel using many processors. The formula for "speedup" is:

$$S = \frac{T(1)}{T(J)}$$

S = the "speedup." The $T(1)$ is the time required to execute the program with a single computer, while the $T(J)$ is the time required to execute the program using a (J) multiple number of computers in parallel.

Amdahl worked for IBM in developing the famous IBM 704, 709, and 7030 mainframe super computers. In

Sandia National Laboratory located in Livermore, California, is one of three U.S. Defense Program Laboratories of the U.S. Department of Energy. The other two are Los Alamos in New Mexico where the Manhattan Project created the first two atomic "nuclear fission" bombs, and the Lawrence Livermore Laboratory in California where the fission-type atomic bomb technology was advanced to "nuclear fusion" used by the much more powerful hydrogen bomb (H-bomb). These labs, although owned by the federal government are managed and operated by contract to private corporations. The Lockheed Martin Corporation operates the Sandia facilities. The Sandia laboratory has four major responsibilities, all related to meeting national security needs. These four functions are 1) ensuring the safety, reliability, and security of the nation's nuclear weapons; 2) reducing the nation's vulnerability to other nation's use of weapons of mass destruction; 3) improving and enhancing critical infrastructures, in particular energy; and, 4) addressing any new or possible threats to the nation's security.

Following World War II these Department of Energy laboratories have expanded their responsibilities and assumed the major role in providing integrated systems and engineering support for nuclear weapons and the explosive core used to fire these weapons, and to ensure the nation's security from nuclear attacks.

1970 when IBM did not accept his idea for a new super computer, he left the company and established the Amdahl Corporation located in California. He later founded other related corporations in California. The Sandia National Laboratories in Livermore, California, question the validity of Amdahl's law when dealing with massive ensembles of parallel computers. The equation for Amdahl's law may need some revision for the new hypercube-type processors.

AMPÈRE'S THEORIES OF ELECTRODYNAMICS: Physics: *André-Marie Ampère* (1775–1836), France.

Ampère came from a wealthy French merchant's family who hired a private tutor for his education. He was mainly a "self-taught" young genius who early in life showed talent for mathematics. He taught mathematics in several universities and was honored by Napoleon who in 1808 appointed him as the inspector general of the newly formed French university system. In 1820 his interest was aroused at a demonstration of the emerging field of electricity. He was inspired to learn more and just a week later was performing his own experiments to explore the nature of electricity.

In the early 1820s Ampère based his theories of electrodynamics on how electric currents influence each other and how they interact with magnetism.

Ampère's theory of flowing current and magnetism: *When two parallel wires carry current in the same direction, they will attract each other. And if the current flows in opposite directions in the two parallel wires, they will repel each other.*

Ampère related this attraction/repulsion concept to the two poles of **magnets**, which led to his famous laws developed in 1825.

Ampère's law, part I: *The force of the electric current between two wires (or conductors) will exhibit the inverse square law, which states that the force decreases with the square of the distance between the two* ***conductors****, and that the force will be proportional to the product of the two currents.*

Ampère's law, part II: *When there is an electric charge in motion, there will be a magnetic field associated with that motion.*

Ampère's law is related to induction, which can be expressed as the equation: $d\beta = k\ A\ dl \sin \theta / r^2$, where *A* is the current and *k* is a proportional factor based on either the cm (centimeter) or m (meter) units of the SI system. $d\beta$ is the increase in the strength of the magnetic field due to an infinitesimal increment *dl* in the length of the current element (a wire carrying the current *A*); θ is the angle between the current elements; and *r* is the distance from the element of wire to the part where the field is measured. (Note: the symbol for electrical *current* may be *A* or *I*, depending on the convention used.)

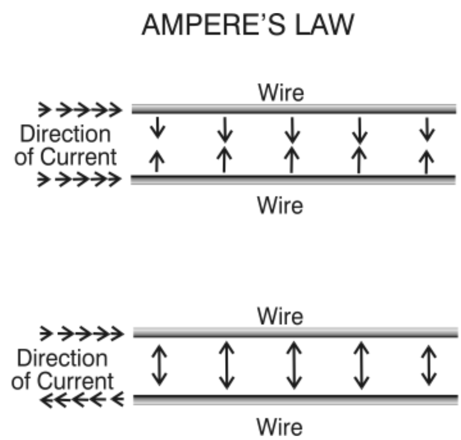


Figure A1. Ampère's Law. For both examples, the strength of the magnetic fields generated between the wires decreases with the square of the distance between the wires.

Ampère devised another law related to the magnetic effects of flowing electrical current in curved wires.

Ampère's circuital law: *The magnetic intensity of a curved or enclosed loop of wire is the sum of the current and can be determined by considering the sum of the*

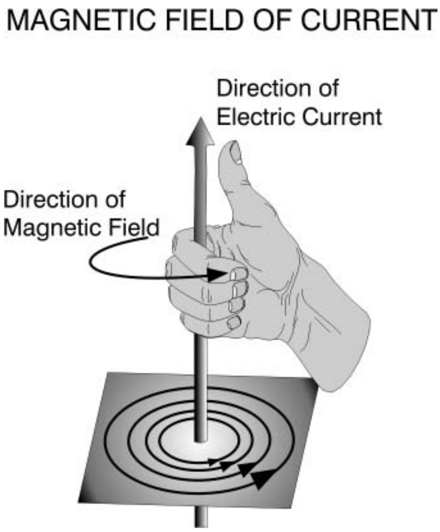


Figure A2. The "right hand rule" indicates the direction of the magnetic field as related to the direction of the flow of current.

magnetic field for each segment of the loop. (This is similar to Gauss's magnetic law for closed surfaces.)

The equation for the circuital law is $B(r) \times 2\pi r = \mu A$ (*B* is the magnetic field at the center of the loop, *r* is the radius of the loop, π and μ are constants, and *A* [or upper case letter *I*] is the electric current). This law measures the strength of the magnetic field in a **solenoid** and determines the strength of the field in **electromagnet**s used in electric generators and motors.

The unit of electrical current known as an ampere or amp was named after Ampère and is given the symbol of A or *I*.

Ampère rule: *The unit of electric current flowing through parallel, straight, long wires in a vacuum produces a force between the wires of* 2×10^{-7} *N* (newtons) *for every meter of wire through which the current flows.*

In other words, it is the measure of the "amount" of electrical current flowing through a wire. As an analogy, consider amps similar to the "amount" of water flowing through a pipe every second. Another way to think of an amp (A) is to count the number of **electrons** that cross a particular point while flowing through a conductor (wire). The rule also states: *One amp equals* 6×10^{18} *electrons passing this point every second.* Electrical appliances are rated according to the number of amps (current) they use (e.g., a TV set uses 3 to 8 amps, a small motor about 2 to 5 amps, a 100-watt light bulb about 1 amp, an electric stove between 10 and 25 amps, or more) (*see also* Faraday; Galvani; Oersted; Ohm; Maxwell).

There is another Ampère rule that states: *The direction of the magnetic field surrounding a conductor will be clockwise when viewed from the conductor if the direction of the current flow is away from the observer* (also commonly known as the "right-hand grip rule").

Ampère's contributions advanced the development of many practical industrial devices that make our lives more enjoyable and easier. For example, he suggested his discovery could be used to send signals, which, over time, became a reality (e.g., telegraph, the radio, TV). Others, including Faraday and Oersted, used Ampère's laws to construct the dynamo (electric generator) and the electric motor. A more recent application is the experimental nuclear fusion project to generate heat for the production of electricity. This process requires very strong magnets to produce the pinch effect that will contain and concentrate the hot plasma gases required for the application of nuclear fusion. However, controlled nuclear fusion to produce electricity has yet to be developed to the point where it is practical. Strong electromagnets are also important for the operation of particle accelerators and magnetic resonance imaging (MRI) and positron emission tomography (PET) medical diagnostic instruments.

ANAXIMANDER'S CONCEPTS AND IDEAS: Natural Philosophy: *Anaximander of Miletus* (c.611–547 BCE), Greece and Turkey.

Although Anaximander's writings were lost, his many original concepts and ideas were well known and reported by other Greek philosopher/scientists. Following are some of his original concepts:

1. Anaximander contested his mentor's (Thales of Miletus)

assertion that water was the main substance (element) on Earth. Anaximander stated that basic matter is indefinite. This led to the Greek atomists' concept of the indivisible atom of matter.

2. The Earth does not "rest" on a body of water, as believed by many in his day. Rather, it is not supported by anything, but it is in equilibrium with other bodies in the universe.
3. He was the first to use a sundial (in Greece) to determine the spring and fall equinoxes.
4. He was the first philosopher/scientist to propose a theory for the origin of humans, as well as how Earth was formed.
5. He determined that the surface of Earth was curved but thought that its shape was similar to a cylinder, not a sphere.
6. Earth's axis was oriented east and west within the cylinder. Anaximander was the first to draw a map of the entire world as known in his day.

ANDERSON'S POSITRON THEORY: Physics: *Carl D. Anderson* (1905–1991), United States. Carl Anderson shared the 1936 Nobel Prize with Victor Franz Hess, who discovered cosmic rays.

> *Cosmic rays passing through a cloud chamber produce tracks of negative particles deflected in one direction (electrons), while producing tracks of particles with equal curvature and equal mass in the opposite direction. Both are deflected by a magnetic field. These particles can be only positive-type "electrons." Thus, they are new elementary particles called a positron.*

In 1932 Carl Anderson's concept of a positive electron (positron) was verified by Patrick Blackett (1897–1974) and Giuseppe Occhialini (1907–1993). This conclusion was arrived at by basing it on Paul Dirac's (1902–1984) theory, that the **positron** was the equivalent in mass but opposite in charge to the electron. Thus, it is an antiparticle, and when considered by itself, it is stable. However, when a positron collides with an electron, they annihilate each other to form a photon (quantum unit of light). In the early 1930s this discovery was followed by nuclear physicists realizing that the nuclei of an unstable element (radioactive nuclei) consists primarily of neutrons and protons and will, during radioactive decay, produce four (instead of the previously thought three) basic particles, namely, 1) the alpha particle (similar to a helium nucleus); 2) the beta particle (similar to a negative electron); 3) the positron (similar to an electron, but with a positive charge); and 4) the gamma ray (similar to a high energy X-ray).

The positron is considered **antimatter** instead of normal matter that led to speculations that there might possibly be an "anti-universe" somewhere consisting of antimatter. This is just that—speculation, not a proven fact. Anderson later discovered what is called the *mu-meson* that was predicted by Hideki Yukawa. It is now called the **muon** whose nature and role in nuclear physics are not yet completely understood. Anderson's use of the **cloud chamber** and his discovery of two new particles opened the path to the exploration and understanding of numerous subnuclear particles.

See also Dirac; Yukawa

ANDERSON'S THEORIES AND MODEL: Theoretical Physics: *Philip Warren Anderson* (1923–), United States. Philip Anderson shared the 1977 Nobel Prize in

Philip Warren Anderson was born on December 13, 1923, and raised on a farm in Crawfordville, Indiana (near Indianapolis). He grew up during the Great Depression. His family moved to Urbana, Illinois, where he attended school. His grandparents and parents were educated and had many friends who were scientists. As a young man, Anderson did extensive reading and was influenced by a high school mathematics teacher. After graduation from the university high school in Urbana he received a national scholarship to Harvard. During the war years of 1940 to 1943 he majored in "electronic physics" and in 1943 was employed by the Naval Research Laboratory to work on the then-secret radar project. Anderson attended graduate school in 1945–1949 where he made many friends and studied with some famous physicists. In 1949 to 1984 he worked in Bell Labs (now Lucent Technologies that was acquired by the Alcatel Corporation) and is still a consultant to the lab. In 1967 he became a professor of theoretical physics at Cambridge University, and in 1977, along with two other scientists, was awarded the Nobel Prize in Physics. Philip Anderson is well known for his works in magnetic superconductivity and quantum disorder in systems and related areas. He has received many awards over the years.

Physics with John Van Vleck and Neville Mott for investigations of the electronic structure of disordered magnetic systems as related to semiconductors.

Anderson's "superexchange" theory: *This theory explains how the different spins of magnetic atoms in a crystal interact with nonmagnetic atoms that are between the magnetic atoms within the crystal.*

This theory led to theoretical statements related to superconductors and antimagnetism.

Anderson's model describes what takes place when a metal, particularly a semiconductor, acts when "impure" atoms are present. This is of importance to the modern semiconductor industry because the semiconductor's capacity is dependent on the type and amount of impure atoms present in the semiconducting element such as silicon and germanium.

Anderson's localization is based on the idea that extended states of matter be localized by the presence of disorder in a particular system. Again, this deals with impurities in crystals as related to superfluidity and superconductivity at extremely low temperatures. This is related to the unique characteristic of heavy helium (H-3) at low temperatures that behaves in an unusual fashion by climbing up and over the sides of a beaker when at near absolute temperatures.

The Anderson–Hamiltonian theory describes how electrons behave in a metal undergoing a transition phase.

Anderson's work in quantum relationships as to how the structure of magnetic and electronic structures affect disordered systems provided the information needed for the development of electronic switching and magnetic memory disks used in modern computers.

ÅNGSTRÖM'S PRINCIPLE OF SPECTRUM ANALYSIS AND RELATED THEORIES: Astronomy and Physics: *Anders Jonas Ångström* (1814–1874), Sweden.

Ångström grew up in a simple home in Sweden where his father was a chaplain. He studied and taught physics at the University of Uppsala. He received his doctorate from the university in 1839 followed by a professorship and in 1858 became chairman of the university's physics department.

In 1853 Ångström published *Optical Investigations* where he compiled a list of his measurements of over one thousand atomic spectra lines that were visible for both the gas and the types of electrodes used in the analysis. This work led to his principle related to spectrum analysis that states: *A hot gas will emit light at exactly the same wavelength at which it absorbs light when cooler*.

This principle was formulated from his work with spectral analysis and led to his analysis of the sun's light spectrum. In 1868 he published *Researches on the Solar Spectrum* based on his observations leading to his conclusion that hydrogen gas is present in the sun because it showed up in his analysis of the sun's spectrum. This work enabled him to demonstrate that the spectra of alloy metals are of a composite nature. In other words, the metals that compose the alloys show up in the analysis as unique individual spectral lines. He was also the first to view and analyze the spectrum of the aurora borealis, also known as the northern lights.

ARAGO'S WAVE THEORY OF LIGHT AND ARAGO'S DISK: Physics: *Dominique Francois Jean Arago* (1786–1853), France.

After discovering chromatic polarization of light in 1811, Arago investigated the idea proposed by the French physicist A. J. Fresnel that light was a wave. This was contrary to the theory of other physicists of the day, including Pierre de Laplace and Jean-Baptiste Biot, that light was of a corpuscular nature and required a medium (the aether or ether) through which to travel. Arago set up an experiment to prove the theory that *light travels through air and media with different densities in waves*. He did this by measuring the speed of light in air and water. Later, after Arago's death, Jean Foucault and Armand Fizeau proved his theory correct. Today, light is considered both a wave and particle (photon), and there is no aether in space.

Arago also discovered how to produce magnetism by wrapping a wire that is carrying electricity around a cylindrical piece of iron. This discovery led to the development of the electric motor, the dynamo, solenoid, and other modern electrical devices.

Arago's disk was a device consisting of a copper disk suspended above, but in close proximity to, a compass. When the disk is spinning, it deflects the compass needle. This is another example of the phenomenon known as Ampère's electric/magnetic induction.

Arago was interested in astronomy and discovered the sun's chromosphere and assisted Urbain Leverrier (1811–1877) in the discovery of Neptune. In his later life instead of continuing his work in physics, he became involved in politics. He was the government official most responsible for the abolishment of slavery in most of the French colonies.

See also Ampère; Fizeau; Foucault; Fresnel

ARBER'S CONCEPT OF THE STRUCTURE OF DNA: Microbiology: *Werner Arber* (1929–), Switzerland and the United States. Werner Arber and two other microbiologists (Daniel Nathans and Hamilton O. Smith) received the 1978 Nobel Prize for Physiology or Medicine.

Arber was born in Switzerland and graduated from two major universities in his home nation before attending the University of Southern California. He returned to Geneva, Switzerland, where he served as professor of microbiology from 1960 to 1970.

He experimented with bacteriophages (a form of virus) that invade bacteria and may cause hereditary mutations in the host bacteria, as well as undergo similar mutations themselves.

Arber's main concept proposed in 1962 relates to the use of a specialized enzyme that can destroy invading phage viruses by cutting up and separating their DNA molecules into smaller pieces. Further, these "restriction enzymes" always attack the DNA at precise and predictable locations on the molecule, which allows the smaller strands of DNA to be reformed in combinations during what is now called "genetic engineering." This is possible because the bits of DNA that are separated are somewhat "sticky" and can be made to combine with other "sticky" bits of DNA at different sites on molecules.

This process is used in the treatment of genetic diseases (although not always successfully), the cloning of plants and animals (also not always successfully), the use of DNA as evidence in legal proceedings, and the mapping of genes in the Human Genome Project. The main benefit of Arber's discovery is its use as a "tool" for further genetic research. The benefits of genetic engineering are mixed, and much research is still needed to make all its promises a reality.

See also Delbrück; Lederberg

ARCHIMEDES' THEORIES: Mathematics: *Archimedes of Syracuse* (c.287–212 BCE), Greece.

Archimedes was an accomplished theoretical and applied mathematician who developed "thought" experiments to test some of his ideas and then expressed their results mathematically. He actually did not conduct controlled experiments as we think of the process today. Only a few of his many theories and accomplishments are explored.

Archimedes' theory of "perfect exhaustion" (calculation of pi): Archimedes was not the first to recognize the consistency of the ratio of the diameter to the circumference for all circles or to attempt the calculation of **pi** as this ratio has became known. Objects of differing shapes and how their dimensions were related intrigued ancient Stone Age people. They realized straight lines do not exist in nature and recognized curved lines in the shape of rocks, plants, animals, and other objects. By about 2000 BCE humans recognized and roughly calculated the relationship of a circle's measurement in the sense that the larger the circle, the greater is its circumference. By the era of the ancient Greeks, mathematicians understood this ratio was consistent for all circles because they measured and compared the diameters and perimeters of various circles. Soon after, this constant irrational number was given the Greek symbol π (pi).

Using his knowledge of the geometry of many-sided plane figures, such as squares and multiple **polygons**, Archimedes proposed his theory of *perfect exhaustion*, which he demonstrated by drawing a circle and inscribing several polygons on the inside and outside of the circle's circumference. At first, he used polygons with just a few sides. Later he used multiple polygons with as many as ninety-six or more sides. This is often referred to as *perfect exhaustion* because Aristotle used polygons with larger numbers of sides. Theoretically, a polygon with an infinite number of sides could be used. Through the use of geometry and fractions, Archimedes measured the inside polygons and compared them with the measured outside polygons. He concluded that the polygons

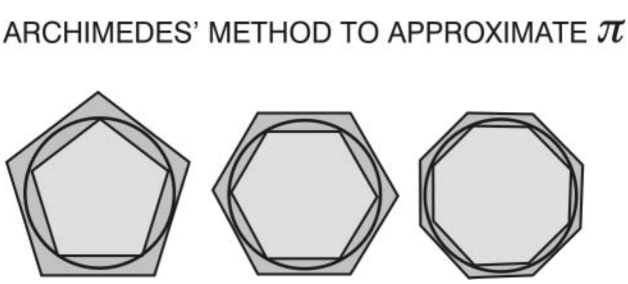


Figure A3. Artist's example of Archimedes using geometry for "Perfect Exhaustion" to estimate pi.

touching the circle on its outside circumference (perimeter) were slightly larger than pi and that the polygons touching the inside of the rim of the circle were slightly smaller than pi. Therefore, pi must be a value somewhere between these two measurements. His value for pi was 3.14163, which he calculated as the figure between the inner and outer polygons ($3_{10/71} < \pi > 3_{1/7}$). His figure for pi has been used for many hundreds of years and was developed by using Euclidean plane geometry. This method of using geometry to calculate pi has physical limitations for arriving at the correct ratio.

Later mathematicians used algebra, which enabled the calculation of a more accurate value for pi. With the invention of fast computers, pi has been run off to several hundred thousand decimal places in a few hours. Yet one could run off pi on a computer forever and still never reach a final number to make pi come out even, because it is an **irrational number**.

Archimedes' theory for the volume of spheres: *The volume of a sphere is two-thirds the volume of a cylinder that circumscribes (surrounds) the sphere.*

It is said that Archimedes wanted this theorem inscribed on his tombstone. Historically, measuring the volume of a sphere was difficult, whereas measuring the volume of a cylinder was easy. Therefore, if one knew the volume of a cylinder that surrounded a sphere, its volume could be determined.

Archimedes' theory of levers: *The mechanical advantage of a lever is due to the ratio of the weight (load) to the action (effort) required to move the load, which is determined by measuring the distance the effort moves from the central point (fulcrum) divided by the distance the load moves from the central point.*

Humans have used the simple lever since prehistoric times. How people learned to take advantage of this simple lever is unknown, but evidence exists that ancient people were aware of the advantage of using sticks for digging and moving heavy objects by prying them with sticks. Archimedes was the first to calculate the ratio of the distance between a force and a weight, separated by a fulcrum. The placement of the fulcrum in relation to the force and weight determined the ratio for the mechanical advantage. Archimedes used his knowledge of geometry and mathematics to calculate the mechanical ratio for several simple machines. For the simple lever, he believed the advantage was the ability to move very heavy loads with little effort. Most of his demonstrations of mechanics dealt with the simple lever. His major demonstration was the raising of a large ship by pushing down on one end of a large lever that he had designed.

Archimedes' concept of the inclined plane: *It is easier to move a load along a long, sloping ascent of a given height than it is to move a load of the same weight along a shorter but steeper ascent to the same height.*

Archimedes knew the mechanical advantage of rolling objects up a long inclined plane of a given height rather than lifting them vertically for the same height. He applied the concept of an inclined plane as a means of raising water in a well up to the surface. He wrapped an inclined plane device around a central shaft to form a "water screw," which was placed with one end in the well and the other on the surface where the water was to be used. When turned by a crank handle, this "helical pump" enabled one man to lift water more efficiently than with any other pump then known. Remarkably, it is still used, twenty-three hundred years later, in Egypt and other parts of the world.

Archimedes also developed catapults, cranes, pulleys, and optical devices that consisted of a series of shiny metallic mirrors that reflected and concentrated rays of the sun. All of the devices are believed to have been used to defend his city of Syracuse

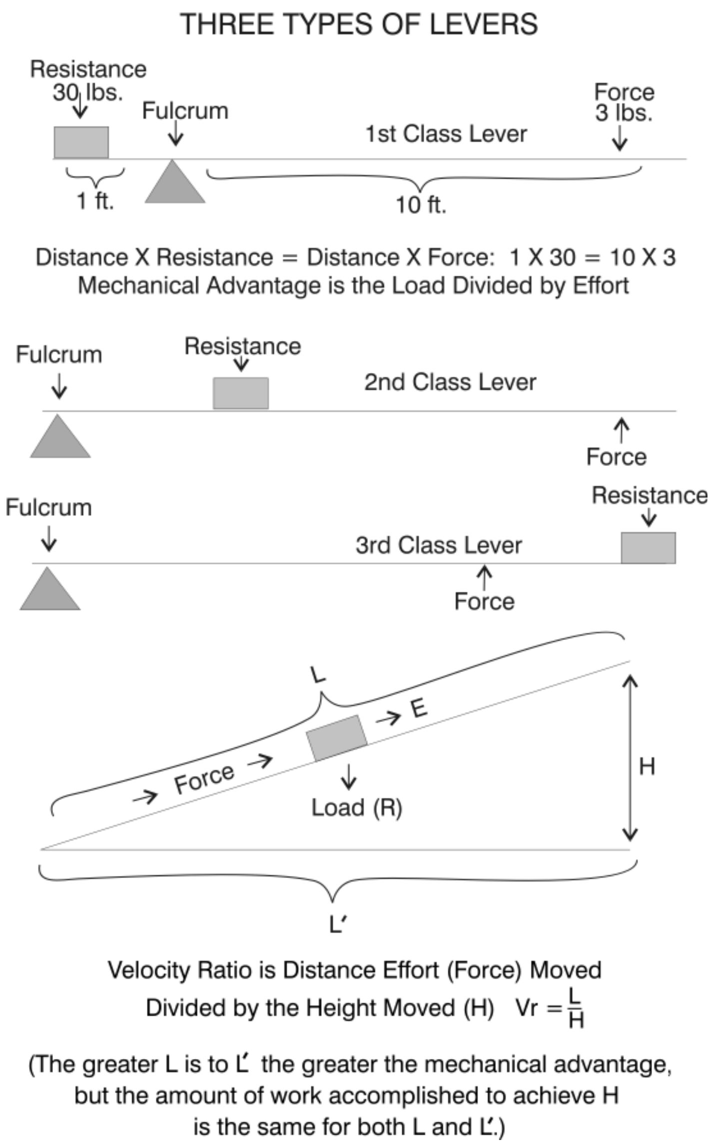


Figure A4. Archimedes' Theory of Levers. Humans used levers for centuries and intuitively knew their advantage, but the theory was not formalized until Archimedes stated it.

from Roman invaders. Although not the first to use his knowledge of physics and mechanics in the name of war, Archimedes was one of the most successful.

Archimedes' concepts of relative density and specific gravity: *The compactness of an object is related to the ratio of its weight divided by its volume.*

Archimedes used his concept of buoyancy to measure the relationship between the weight and volume of an object. No discussion can omit the famous story of how Archimedes gained insight into the concept of density and specific gravity. As the story goes, King Hiero of Greece asked Archimedes to ascertain whether a gold crown he commissioned from a goldsmith was pure gold or whether silver was substituted for some of the gold. Archimedes pondered the question while taking a public bath. He lowered himself into a bath filled to the brim. As he sank deeper into the bath, more and more water spilled over the sides. He immediately grasped the significance of this phenomenon, jumped out of the bath, and ran naked down the street shouting "Eureka! Eureka!" ("I have found it! I have found it!"). He proceeded to fill a bucket to the brim with water into which he lowered the crown, catching and measuring the volume of the water that overflowed. He did the same with equal weights of gold and silver. Because gold has a greater density than silver, the ball of gold was smaller; thus with a smaller volume less water spilled over the edge of the bucket. Once he could measure the volumes of the water representing the volumes of the gold, silver, and the crown, all he needed to do was to divide the figures obtained for the weight of each item by their volume of water and calculate a ratio representing their comparative densities. He could then determine how much of the crown was gold and how much was silver. (Supposedly, the crown was not pure gold, and the goldsmith was executed.)

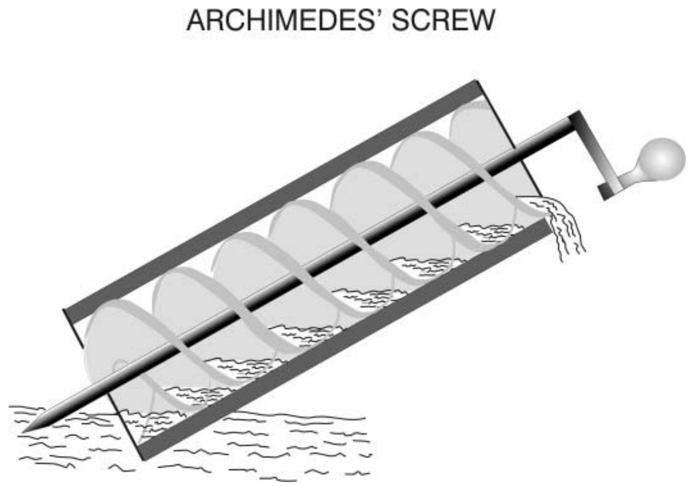


Figure A5. Archimedes' "Screw" used the concept of an inclined plane wrapped around a central shaft to form a "helical pump" that one person could use to raise water from a well.

His principle led to the expression of density as the weight (mass) of an object divided by its volume *($d = m/v$)*. Specific gravity is the ratio of an object's density to that of some standard. For liquids, water at 15°C temperature is the standard for specific gravity expressed as 1.0. (Any object denser than water would have a specific gravity greater than 1.0 and would sink, whereas any object with a density less than 1.0 would float in water.) For gases, dry air is used as the standard pressure and temperature. Specific gravity is easier to use than density for making calculations because it is the same value in all systems of measurement.

Archimedes' theories, principles, and concepts have been refined over the ages, but his genius has provided the basis for modern-day machinery and instruments.

ARISTOTLE'S THEORIES: Physics: *Aristotle of Macedonia* (384–322 BCE), Greece.

In the estimation of many historians, Aristotle was one of the most influential humans who ever lived. Although he was a philosopher concerned with classes and hierarchies rather than a scientist concerned with observations and evidence, his philosophy, methods of reasoning, logic, and scientific contributions are still with us and continue to be influential. Much of Aristotle's philosophy is related to his four causes: 1) *the matter cause, which makes up all material, including living organisms*; 2) *the form cause of species, types, and kinds of things*; 3) *the efficient cause of motion and change*; 4) *the*

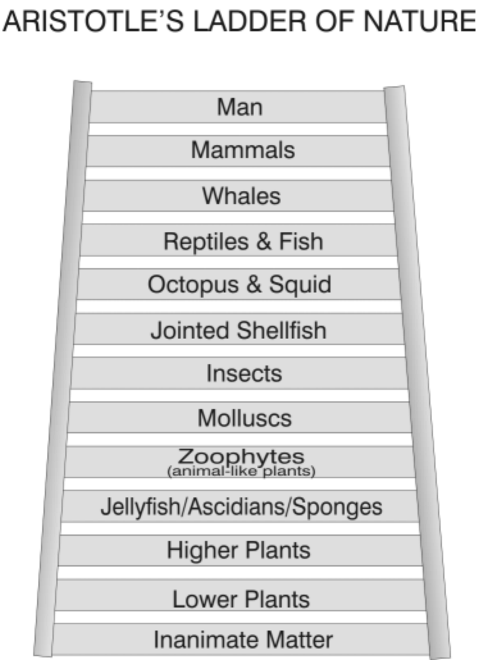


Figure A6. Aristotle's classification (taxonomy) of living things known as the "Ladder of Life"

final cause of development or the final goal of an intended activity (maturity). He related these "causes" to inanimate and animate phenomena. Only a few of Aristotle's theories related to limited areas of science are presented.

Aristotle's topological-species theories: *An ideal form is a living group in which each member resembles each other, but the group is distinct in structure from members of other groups*. His concept can further be stated as *Each living thing has a natural built-in pattern that, through reproduction, growth, and development, leads to an individual type (**species**) similar to its parents*. Aristotle also believed that all living species reproduce as to type (e.g., humans beget humans, cattle beget cattle), but he considered a possible exception to this theory when applied to the lowest of species. He organized species from lowly flies and worms at the bottom, then lower animals, up to mammals, and then humans at the top. Aristotle classified everything and endeavored to write all as a unified theory of knowledge, which preceded Einstein's long-sought grand unification theory by many centuries.

Aristotle's theory of spontaneous generation: *Flies and low worms are generated from rotting fruit and manure*. He based this theory on observations, not experimentation. Later scientists, through the use of simple experimentation, demonstrated "spontaneous generation" of life does *not* exist, at least as expressed by Aristotle and some former scientists (*see also* Leeuwenhoek; Pasteur; Redi).

Aristotle's theory of taxonomy (classification) of living things: *Nature proceeds from tiny lifeless forms to larger animal life, so it is impossible to determine the exact line of demarcation. Reproduction identifies those giving live birth (viviparous) as being mammals and humans, whereas those laying eggs (oviparous) are subdivided into birds and reptiles, and fish and insects*. Aristotle developed an elaborate classification system of nature later called *Aristotle's ladder of nature*. It listed inanimate matter at the bottom, progressing upward from lower plants, higher plants, minor water organisms, shellfish, insects, fish, reptiles, whales, mammals, and finally on the top rung of the ladder, humans.

Aristotle expressed his theory in a graphic structure called *scala naturae* or *chain of being*, better known as "Aristotle's ladder of nature."

Aristotle's three classes of living things: 1) *vegetable, which possessed a nutritive soul*; 2) *animals, who were able to move and thus had a sensitive soul*; and 3) *humans who had intelligence and thus a rational soul, and who also possessed souls of all the types of creatures*.

One of Aristotle's classifications was that male humans had more teeth than did females. As a philosopher concerned with the meaning of classes and hierarchies rather than a scientist concerned with observations and evidence, neither he nor anyone else at that time bothered to count the teeth in men and women. Regardless, "man" was at the top class with a rational soul.

Aristotle's concept of reproduction: *An invisible "seed" of the most rudimentary structure was imparted by the male to join a female egg to produce an offspring of the same species*.

Some philosophers and scientists of Aristotle's day (and later) believed the "seed" (sperm) was a tiny, invisible person or animal that grew larger once it joined with the female egg. Aristotle concluded this by observations made while dissecting and studying fertile chicken eggs at different stages of embryonic development. He rejected most theories about reproduction proposed by previous philosophers, including those that posited that the sex of an embryo is determined by how it was placed in the womb, a seed originates as a whole body, and the embryo contains all of the adult and body parts (preformationism).

Aristotle's laws of motion: 1) *Heavy objects fall faster than lighter ones, and the speed of descent is proportional to the weight of the object.* 2) *The speed of the falling object is inversely proportional to the density of the medium through which it is falling.* 3) *An object will fall twice as fast as it proceeds through a medium of half its density. Thus a vacuum cannot exist because the object would proceed at an infinite speed.* This law is one of the few examples indicative of Aristotle's concern with the quantitative nature of things. Unfortunately, he did not verify his insights by experimenting and making measurements. Although his laws of motion were incorrect, they were accepted for many years and provided the background for which Galileo and Newton revised Aristotle's original concepts.

Aristotle's concepts of motion were rather simplistic. When asked why things move, he responded simply that it is because something moves them. He considered three types of motion on Earth: 1) the motion of living things that is voluntary; 2) objects that are moved tend to return to their a natural position of rest; and 3) when something is set in motion its motion will cease once the "mover" is eliminated. These ideas are expressed as Aristotle's laws of motion: *Violent (forced) motion will always be displaced by natural motion that ends in a state of rest. The speed of a moving object is directly proportional to the force applied to it.* In simple language this means if you cease pushing an object, it will stop moving. Philosophers and scientists, before as well as after Aristotle's time, could not accept the concept of action (force) at a distance, such as gravity. There had to be something in contact with the object that would force the object to move, and it could not just be "spirits," as some believed, but rather something physical. To Aristotle, all motion was self-explanatory because all bodies sooner or later came to their natural place of rest in the universe. He explained his theory somewhat in this way: Once "impulse" was given to a stone by throwing it up in the air, this impulse was transferred to the air in tiny increments, which kept pushing the stone up. These "air impulses" pushing the stone upward became weaker as the stone rose, and now the natural motion of the stone returned it to the ground in a straight line, and finally to its natural state of rest. When the "impulse" completely stopped, so did the object's motion.

Aristotle applied his concepts of motion to his observations of heavenly bodies. His theory states: *Heavenly bodies move in perfect circles rather than in straight lines as bodies do on Earth. Thus, heavenly bodies are not composed of the four earth elements but rather a fifth element called aether.* This concept that heavenly bodies and bodies on Earth obey separate laws was followed by scientists until Newton's time. Celestial bodies were "pure," whereas those on Earth were subject to death and decay. Aristotle's theory of the prime mover, impulse, and motion came very close to the modern physical law of conservation of momentum (*see also* Galileo; Newton).

Aristotle's concept of infinity: *Because the universe is spherical and has a center, it cannot be infinite. An infinite thing cannot have a center, and the universe does have a center (Earth). Therefore, infinity does not exist.*

Most philosophers of Aristotle's day believed the universe was composed of crystalline concentric spheres with the earth at the center; therefore, the universe was finite.

Aristotelian logic is still taught in high school and university courses in dealing with reasoning and logic and is often used by debaters. The word ''logic'' is derived from the Greek word *logos,* meaning a form of reasoning using speech. Several Greek philosophers before Aristotle had developed forms of logic, but it was Aristotle who advanced the study and whose writings still exist. It is from these records that we have learned about the basic logic called ''Aristotelian syllogism.'' A syllogism is a form of verbal deductive reasoning that contains three parts, 1) first major premise; 2) second premise (both are assumptions); and 3) a conclusion drawn from 1) and 2). For example: 1) All warm-blooded land animals with four legs are mammals. 2) Horses are warm-blooded land animals and have four legs. And, 3) therefore, all horses are mammals. Note that both 2) and 3) are consistent with and contained within 1), the major assumption. Syllogistic logic can be either positive [*all* 1) are 2)] as is the above syllogism, or negative [*no* 1) are 2)] as follows: 1) All warm-blooded mammals can run. 2) Birds are warm blooded and can run. And, 3) Therefore, birds are mammals. Thus, a negative syllogism is flawed logic. It is a type of fallacious statement often used by people with the intent to deceive.

Somewhat the same argument was used to negate the existence of a void, or vacuum. Accepting concepts such as infinity and vacuum was beyond the philosophical reasoning of people in Aristotle's time. It was not until the sixteenth century, when Copernicus provided credible evidence that the earth was not the center of the **universe**, that this geocentric concept was overcome.

Aristotle's theory of the matter and the aether: *Because all celestial bodies move in perfect circles, there must be a perfect medium for this to occur.*

This perfect medium that enables circular motion is known as the **aether**, which also has circular motion. Aristotle accepted the classification of elements as devised by Empedocles (c.490–430 BCE) and others that placed all things into four elementary groups: earth, water, fire, and air. He saw the need for a fifth class of matter when addressing the heavens. Until Newton's time, scientists continued to accept the concept of aether (or *ether*, the Greek word for "blazing"). In its more sophisticated form, it was referred to as the "fabric of space." The concept of an ether existed into the days of early radio. It was popular to believe that radio signals (and other electromagnetic waves) were transported by something in space similar to the way sound is carried by air. In Aristotle's time, people did not believe the sun's heat could reach Earth without some form of "matter" transporting it.

See also Maxwell

ARRHENIUS' THEORIES, PRINCIPLES, AND CONCEPTS: Chemistry: *Svante August Arrhenius* (1859–1927), Sweden. Arrhenius was awarded the Nobel Price for Chemistry in 1903.

In 1883 Svante Arrhenius proposed two related theories of dissociation. One deals with what occurs when substances are dissolved in solutions; the other explains what happens when a current of electricity is passed through a solution.

Arrhenius' theory of solutions: *When a substance is dissolved, it is partly converted into an ''active'' dissolved form that will conduct a current.* Arrhenius' theory is based on the concept that **electrolytes** in solution dissociate into atoms (*see* Figure A7, and *see* Faraday).

Arrhenius' theory of ionic dissociation: 1) *When an electric current is passed through molten salt (sodium chloride, NaCl), it dissociates into charged ions of* Na^+ *and* Cl^-. 2) *Positive charged* Na^+ *ions are attracted to the negative pole (**cathode**) and deposited as neutral atoms of sodium metal, and the negative charged ions of* Cl^- *are attracted to the positive pole (**anode**) and changed back to neutral atoms of chlorine, as the gas molecule* Cl_2.

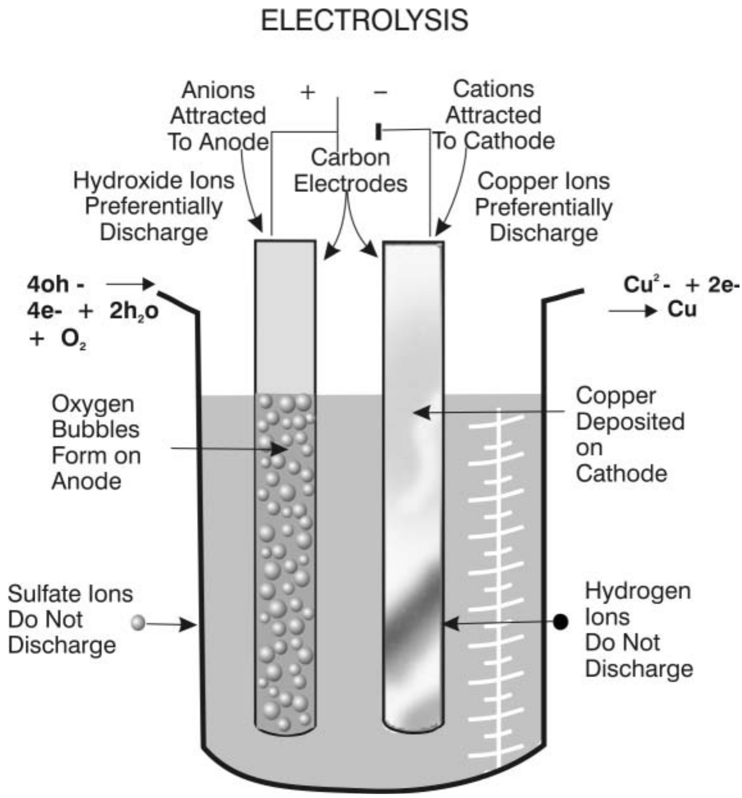


Figure A7. The positive ions are attracted to the negative cathode, and the negative ions are attracted to the positive anode. The ions lose their electrons to form neutral atoms through a discharge of the current between the electrodes and through the electrolyte, which is an ionized compound in solution that can carry electricity.

Once the atoms are "dissociated" into **ions** in a liquid and become an electrolyte solution, an electric current can pass through the solution, producing a completed electric circuit.

These theories are related to electrolysis and are important to many industrial processes today, including electroplating. For instance, ionic dissociation is one way to produce chlorine and sodium from common salt (NaCl). The dissociation of substances, such as $NaNO_3$, separates the compound molecule into Na (sodium metal) and NO—(the negative nitrate ion). A similar process occurs when electroplating gold and chromium, and other metals (*see also* Faraday).

Arrhenius' principle of acid-base pairs: *When an acid splits, it will yield hydrogen ions (H^+). When a base breaks apart, it will yield hydroxyl ions (OH^-).* Arrhenius extended his concepts about ionic dissociation to include his theory related to acids and bases. In general terms, this principle has been broadened to make it more useful for chemists, who still speak of *acid-base pairs*. This broadened principle refers to the transfer of a proton from one molecule to another: *The molecule that gave up the proton is the **acid**, and the one receiving the proton is a **base**.* The process is used in industry to produce acids and alkaline (basic) chemicals.

Arrhenius' rate law: *The rate of a chemical reaction increases exponentially with the absolute temperature.*

Arrhenius and others based this phenomenon on their observations that when the temperature rises, the rate (speed) of chemical reactions increases; conversely, when the temperature cools, reactions slow down. They noted this for such things as spoilage and decomposition of fruits and vegetables in hot climates, though their usefulness can be extended by refrigeration. Also, bread rises faster in a warm environment, substances dissolve faster in warm water, and so forth. Arrhenius' rate law can be expressed mathematically: Rate = A exp(−B/T), where *A* and *B* are constants that differ from one reaction to another, and *T* is time. The value of this equation is its use in generalizing the concept based on the fact that most chemical reactions occur at room temperatures of about 20°C, and a rise of 10°C will double the rate of the reaction.

Arrhenius' theory of panspermia: *Life came to Earth as a bacterial spore or other simple form from outside the solar system.*

After Redi and Pasteur discredited the theories for spontaneous generation, other theories for the origin of life were postulated, including theories of life arriving on Earth from outer space. Arrhenius proposed a theory, called *panspermia*, for the beginning of life on Earth from extraterrestrial origins. This theory is gaining some new proponents since it was reported that simple organic molecules were found in some meteorites, possibly from Mars, that landed on the ice sheets of Antarctica. A modern version of the theory is that pre-bacteria-type organisms capable of reproducing are universal and develop within a suitable environment anywhere in the universe (*see also* Hoyle; Pasteur; Redi; Spallanzani; Struve).

Arrhenius' theory for the greenhouse effect: *The percentage of carbon dioxide in the upper atmosphere regulates the temperature, which may be the cause of the ice ages.*

In 1967 when the unmanned lunar lander *Surveyor 3* landed on the moon, it contained a TV camera that was recovered more than two years later by two astronauts. They brought the camera back to Earth for testing. When it was examined in a sterile environment, scientists were surprised to discover that specimens of the bacteria *Streptococcus mitis* were still alive and active. At first, they were puzzled about the origin of these bacteria and then realized they must have been in the camera before it was launched to the moon. It seems amazing that bacteria can exist in the cold/hot vacuum of space, but this does not seem to be a problem for bacteria that are found living in extreme environmental conditions on Earth. When some species of bacteria are faced with lack of water and are exposed to extreme temperatures for extended periods of time, they break open and release proteins, sugars, and other chemicals that act to protect some of the surviving bacteria. If there are enough bacteria in the colony and enough protective substance is released, some of the protected bacteria will survive. These protective substances are called *cryoprotectives.* Some surviving bacteria form an endospore into which the original cell reproduces its chromosomes. These inner endospores formed by the original cell are protected by a surrounding wall, while the outer original cell may perish. The protected endosperm will survive most conditions, including boiling water. There are many cases where bacteria have survived for thousands of year on Earth in very inhospitable environments. One example is the bacteria found in the gut of a bee that was preserved in amber as a fossil for about forty million years. Actual bacteria, spores, or viruses (or any other forms of life) from distant outer space have yet to be found, in spite of advocates of extraterrestrial life found on Earth by people who believe in science fiction.

The theory of panspermia as the basis for the origin of life and its evolution on Earth is now considered a hypothesis that might be tested. The revival of this old theory of life on Earth originating from outer space as proposed by Arrhenius and others is based on some unusual discoveries.

Over eighty years ago, Arrhenius was one of the first to relate carbon dioxide to global climate changes. Although he was unable to establish an exact relationship between carbon dioxide and atmospheric temperatures, he considered the cooling and warming effects of CO_2 as evidence for the cause of the past ice ages. His theory is based on the belief that CO_2 in the atmosphere does not absorb the energy from the sun that arrives on the surface of Earth in the form of light and infrared (heat) radiation. In addition, the energy radiated from Earth is in the form of infrared radiation that is absorbed by CO_2, acting as a blanket thus creating a *greenhouse effect*. This theory is still controversial; however, evidence indicates that there is a slight increase in the levels of atmospheric CO_2 that may, or may not, have a slightly more warming than cooling effect on Earth (about 1.5°C in the twentieth century). The increase in water vapor plus methane from industry, decaying of organic matter, and animal flatulence also contribute to a greenhouse effect. Another theory states the massive ice age six hundred million years ago, when Earth was a complete ice planet, ended as trillions of simple organisms produced enough carbon dioxide to create a greenhouse effect. This may have resulted in the melting of the ice that covered Earth, thus permitting the evolution of higher forms of life. Carbon dioxide also increases plant growth on Earth, which provides food for a more diverse animal kingdom.

See also Rowland

ASTON'S WHOLE NUMBER RULE: Chemistry/Physics: *Francis William Aston* (1877–1945), England. Francis Aston received the 1922 Nobel Prize in Chemistry.

Aston began his career in chemistry and physics just before the turn of the twentieth century. He devised a new and improved pump used to create a vacuum inside glass tubes that were used in gas discharge experiments. One area he explored was *Crookes dark space* found in these discharge tubes. He discovered a phenomenon now known as *Aston dark space*. This work led to his discovery of two isotopes of neon gas, each with a different atomic mass. Further work led to his invention of the mass spectrometer that uses electromagnetic focusing to detect any slight difference in the mass of atoms of the same element (isotopes). This work led to Aston's formation of the whole number rule, that in essence, states: *The mass of the oxygen isotope is defined as a whole number, and all the other isotopes of elements have masses that are very nearly whole numbers.*

Aston invented the mass spectrograph, an instrument that uses electromagnetic focusing to separate **isotopes** of the same element by slight differences in their **atomic weights**. The **nuclei** of atoms of a specific element are composed of both positive **protons** and neutral **neutrons**. The number of protons determines the chemical identity of the element, which does not change, whereas the number of neutrons can be more or fewer than the number of protons. This explains the formation of isotopes of the same element with different atomic weights. This difference in weight is very slight and was not successfully detected until the development of the spectrograph. Aston used his instrument to measure this minute difference in atomic weights and to separate and identify 212 isotopes of nonradioactive elements. From his research he devised the *whole number rule*, which advanced the fields of inorganic and nuclear science.

Aston's invention of the mass spectrometer and identification of isotopes for atoms has been invaluable to science. In his personal life he excelled in such sports as tennis, swimming, rock climbing, and skiing. He was also an accomplished musician playing the violin, cello, and piano.

ATOMISM THEORIES: Physics. Theories related to the nature of atoms and related scientists listed chronologically.

Theories of atomism date back to the fifth century BCE, when philosophers conceived the idea that all matter was composed of tiny, indivisible particles. In ancient times these ideas were classical philosophical theories deduced by reason and logic, not by empirical or experimental evidence. The word *atomos* is derived from two Greek words: *a*, which means "not," and *tomos*, which means "cut." In other words, you cannot cut it, or it is indivisible. Several examples of atomic theories follow:

Leucippus' atomic theory: *Leucippus of Miletus* (c.490–430 BCE), Greece. *All matter is composed of very minute particles called atomos. They are so small that there cannot be anything smaller, and they cannot be further divided.*

Not much is known about Leucippus, but he was the first to be credited with originating the atomic theory, giving the concept the name *atom* and describing the indestructible nature of atoms. One of Leucippus' students was a philosopher named Democritus, who is also credited with the "atomic concept."

Zeno's paradox: *Zeno of Elea* (c.495–430 BCE). One of Zeno's theories stated that *conclusions could be reached by reason even when there was contradictory sensory evidence.* He used paradoxes to present his hypotheses that motion and distance could be divided into smaller units *ad infinitum*. His most famous paradox was used by other philosophers and scientists to explain the concept of the division of matter into smaller and smaller particles while never reaching a final indivisible particle (*see also* Zeno).

Democritus' theory of atoms: *Democritus of Abdera* (c.460–370 BCE), Greece. It is assumed that Democritus and others who followed questioned Zeno's paradox as a rational way of looking at nature in the sense that the division of space and motion could be divided indefinitely, and perhaps there was a final limit to the point of indivisibility. He further developed the atomic theory of his teacher, Leucippus. Democritus and other philosophers considered what would happen if a person took a handful of dirt and divided it by half, then divided that half into half, and continued dividing it by halves. Eventually a point would be reached at which a single tiny speck of dirt that could no longer be divided was all that remained. The result was considered, on a philosophical basis, to be the indivisible atom of dirt. Democritus also theorized *these tiny "atoms" of matter unite to form larger masses, and the large mass could fly apart and the smallest particles would still be the tiny atoms.* This led to his theory that *nothing can be created out of nothing*, which was the precursor to the basic physical law of conservation of matter and energy.

Aristotle's theory of the atom: *Aristotle* (384–322 BCE), Greece. Aristotle recorded much of the philosophy of Democritus. He also credited Democritus with the concept of the indivisible atom and accepted it as a rational, logical, philosophical explanation (*see also* Aristotle).

Epicurus' theory of the atom: *Epicurus of Samos* (c.341–270 BCE), Greece. Epicurus kept the atomism theory current by demonstrating how it could be the basis for perceiving reality and eliminating superstitions—the Epicurean concept of "just being happy" and living a good life without fear. Later, the Romans adopted this philosophy of the "good life." The modern word *epicurean* is derived from Epicurus, whose theory stated that *atoms were forever in constant motion, perceivable, and thus "deterministic."* Although he disputed Democritus' concept of atoms as having "free will," Epicurus was the first to suggest atomic or molecular motion, which later developed into the concepts of kinetic energy, heat, and **thermodynamics**.

Lucretius' theory of atoms: *Titus Lucretius Carus* (c.95–55 BCE), Italy. Lucretius was a follower of Epicurean philosophy that life's goal should be to avoid misery. His theory was the last of the ancient classical period: *There is a natural origin of all things in the universe, including the heavens, physical objects, and living things, and all things, including living organisms, are composed of atoms of different substances.* Although atoms and molecules could not be seen at this time, his ideas preceded the cell theory and the theory for the chemical basis of **metabolism**. He also preceded Charles Darwin by many centuries with his philosophy that all living things struggle for existence, which is one of the principles of evolution, more accurately stated as "natural selection." Up to this time, the indivisible atom was a concept that usually included inorganic matter. Lucretius is credited as being one of the first to write about the atomic structure of living things, including humans, based more on divine knowledge and his philosophy than on **empirical** evidence.

These ancient classical theories, concepts, and philosophies of atomism were mostly ignored and unexplored for over fifteen hundred years. The more modern atomic theories that developed during later periods are presented alphabetically under the names of the scientists.

See also Bohr; Boyle; Gassendi; Heisenberg; Rutherford; Thomson

THE AUGER EFFECT: Physics: *Pierre Victor Auger* (1899–1993), France

Born and educated in France, Pierre Auger was a professor of physics at the University of Paris who, after World War II, became the director general of the European Space and Research Organization.

Auger discovered the "effect" or "process" that was named after him in the early 1920s. In essence it is a two-stage process that can be stated as: *When an electron absorbs energy from an X-ray photon it will lose that energy as an electron is emitted from an inner shell (instead of a photon) as the atom reverts to a lower energy state.* This results in the emission of an electron representing the energy difference and is known as the Auger effect.

It is well known that the various energy levels of electrons in different shells are discrete and unique to the atoms for each individual element. Thus, the Auger process is the identification of the energy levels, which are signatures of the atoms that emit quanta units of energy. Auger developed a spectroscope capable of using this effect to measure this phenomenon. This spectroscope is useful in the laboratory to provide information about the electron structure of ionized atoms with different atomic numbers (protons). The Auger process is used to identify the "signature" of specific atoms that are emitting quanta of energy, including atoms that make up crystals.

AVOGADRO'S LAW, HYPOTHESES, AND NUMBER: Chemistry: *Lorenzo Romano Amedeo Carlo Avogadro* (1776–1856), Italy.

Avogadro's hypothesis: *If the density of one gas is twice that of another, the atomic mass of particles of the first gas must be twice that of the particles of the second gas.* This relationship between the density and the number of particles in a given volume of gas opened the field of quantitative chemistry, which became a more exact science because it involved the analysis of measurements made of observed phenomena. It enabled molecular weights of different substances to be compared by weighing and measuring the combining substances. Using his hypothesis to compare molecular weights of the oxygen and hydrogen molecules, Avogadro established that it required two hydrogen atoms to combine with one oxygen atom to form a molecule of water. Avogadro also hypothesized that *gases such as oxygen and nitrogen must be composed of two atoms when in their gaseous phase*. He named the particle, which is composed of more than one atom, the **molecule**, meaning "small mass" in Latin. This concept led to the structure of the diatomic molecule for gases (e.g., H_2 O_2 Cl_2).

Avogadro's law: *Equal volumes of gases at the same temperature and pressure contain the same number of molecules, regardless of the physical and chemical properties of the gases*. This is true only for a "perfect gas." Avogadro knew that all gases expand by equal amounts as the temperature becomes greater (assuming that the pressure on a gas remains unchanged). Through some insight on his part, he realized that if the volume, pressure, and temperature were the same for any type of gas, the number of particles of each of the gases, existing under the same circumstances, would be the same. His reasoning that all gases under the same physical conditions have the same number of molecules was based on the fact that all gas molecules have the same average kinetic energy at the same temperature. Other physicists of his day called this unique law *Avogadro's hypothesis*.

The scientists of this period of history did not completely understand this concept and its relationship to the atomic weights of elements. This delayed the use of Avogadro's theories and principles for about five decades until they were rediscovered and applied to modern chemistry. In 1858 the Italian chemist Stanislao Cannizzaro used Avogadro's hypothesis to show that molecular weights of gases could be definitely determined by weighing 22.4 liters of each gas; thus the results could explain molecular structure (*see also* Cannizzaro).

Avogadro's Number: *6.023×10^{23} is the number (N) of atoms found in 1 mole of an element.*

In other words, 1 **mole** of any substance, under standard conditions, contains 6.023×10^{23} atoms. Avogadro's number provided scientists with a very easy and practical means to calculate the mass of atoms and molecules of substances. As an example, the number of atoms in 12 grams of the common form of carbon 12 equals the *atomic weight* of carbon 12 (6 protons + 6 neutrons in the nucleus); thus 12 grams of carbon is equal to 1 mole of carbon. This is expressed as the constant *N* and applies to all elements and also to molecules of compounds.

Scientists assigned the simplest atom, hydrogen, an atomic weight of 1, which then results in the weight of 2 for diatomic molecules of hydrogen gas (H_2). It was determined that at 0°C, under normal atmospheric pressure, exactly 5.9 gallons (or 22.4 liters) of hydrogen gas weigh exactly 2 grams. (In other words, 22.4 liters of any gas, under the same conditions, equals its atomic or molecular weight in grams.) This established that the atomic weight of any element, expressed in grams, is 1 mole. Avogadro's number is one of the basic physical constants of chemistry. Thus, 22.4 liters of any gas weighs the same as the molecular weight of that gas and is considered 1 mole. Two other examples: one molecule of H_2O has a weight of 18 (2 + 16), so 18 grams of water is equal to 1 mole of water; sulfuric acid, H_2SO_4 has the molecular weight of 98 (2 + 32 + 64), so 1 mole of sulfuric acid equals 98 grams of H_2SO_4.

Using this constant makes chemical calculation much easier. All that is needed to arrive at a mole of a chemical is to weigh out, in grams, the amount equal to its atomic or molecular weight. These examples can be changed to kilograms, by multiplying grams by 1000, but they are still equivalent as a molar amount.

Using the *kinetic theory of gases* and the *gas laws*, it is now possible to calculate the total number of molecules in 22.4 liters (1 mole) of a gas. The figure turned out to be six hundred billion trillion, or 600 followed by 23 zeros, or more exactly 6.023×10^{23}.

B

BAADE'S THEORIES OF STELLAR PHENOMENA: Astronomy: *Wilhelm Heinrich Walter Baade* (1893–1960), United States.

Baade's theory of stellar populations: *Population I stars are like our sun and are found in the disk portions of galaxies. Population II stars are found in the ''halo'' region of galaxies.*

As a result of his observations at the Mt. Wilson Observatory located in Pasadena, California, Baade developed the concept of two different types of stars and his theory of galactic evolution, which was based on the following characteristics of the two star populations:

Population I Stars

1. Population I stars are younger halo stars (formed more recently than Population II).
2. Thus, Population I stars have more "heavy metals." "Heavy metals" is a descriptive term for all elements heavier than hydrogen and helium.
3. Population I stars have lower velocities as compared to our sun (disk stars).
4. Orion Nebula is an example of a younger Population I disk with more metals than the sun.

Population II Stars

1. Population II stars are older disk stars (formed early in galactic history). Population II stars have fewer "heavy metals."
2. Population II stars have random orbits and higher velocities than Population I stars.
3. Stars in the "galactic bulge" are old but received heavy elements from **supernovas.**

Baade's theory of star luminosity: *The period/luminosity relationship is valid only for Population II-type Cepheid stars.*

Baade's theory is based on the work of Henrietta Leavitt and Edwin Hubble who determined the relationship of periodicity and luminosity of Cepheid-type stars that vary in brightness. Baade's work, combined with the results of other astronomers, led to methods for determining the distance (in light-years), size, and age (in billions of years) of Andromeda and other galaxies. Baade concluded that the Milky Way **galaxy** was larger than the average galaxy, but, by far, it is not the largest (or oldest) galaxy in the universe.

Baade also theorized that luminosity is related to the mass of stars. In other words, 1) *there are more low-mass stars than bright high-mass stars;* 2) *this determines the ''mass function'' when referring to the number and density of stars;* and 3) *this is similar to the ''luminosity function'' that relates to stars with different luminosities*. This theory eliminates the evolutionary processes of stars and just considers the initial mass function for stars.

In addition, Baade, as well as several other astronomers, developed several theories, hypotheses, and opinions concerning *dark matter*. The phenomenon referred to as the massive amounts of "dark matter" in the universe may be described as two major types: 1) massive compact halo objects (MACHOS) identified as brown dwarf stars, extra large planets, and other types of very compact matter and 2) weakly interacting massive particles (WIMPS) that have not yet been discovered.

Following are some possibilities of why it is believed there is so much dark matter in the universe that falls within the two general categories of dark matter: MACHOS or WIMPS:

1. "Failed stars" called brown dwarfs or large planets similar to Jupiter that have a mass-to-light (M/L) ratio less than the sun. (The sun is considered to have a M/L of 1.)
2. "Stars with low luminosity" have a M/L less than 1 and are thus less massive than the sun. (They most likely make up most of the disk of dark matter in the universe.)
3. "Compact objects" consisting of neutron stars, dwarfs, and black holes that have a high M/L ratio and thus not as many are required to form dark matter.
4. "Strange new massive particles" that are odd, not-yet-discovered, strange bodies that in some way weakly interact with normal types of matter to form dark matter.

Baade's theory of gravitational microlensing: *Gravitational microlensing occurs when one star happens to be positioned in front of another star*.

Baade based this theory on work done previously by Albert Einstein. Depending upon the distance between the two stars and on the positioning of the foreground star in relation to the background star, the background star's image is magnified due to the "gravitational lens" effect of the gravity of the foreground star. This is called *microlensing* because the difference (increase in size) in the image of the background star is often too minute to be observed with a telescope. The chances of actually observing gravitational microlensing are relatively small. Millions of stars must be observed to find a situation that correctly aligns one star of the right type in front of another star. In addition, their masses, distance from each other, velocities, and brightness are limiting factors. Therefore, this phenomenon is more likely to occur when looking edgewise at a galaxy that appears as a flattened disk with a bulge at its center. This "bulge of stars" provides more of an opportunity for seeing stars in alignment and thus the microlensing phenomena. Note: When viewing a galaxy from above or below, it appears as a rather

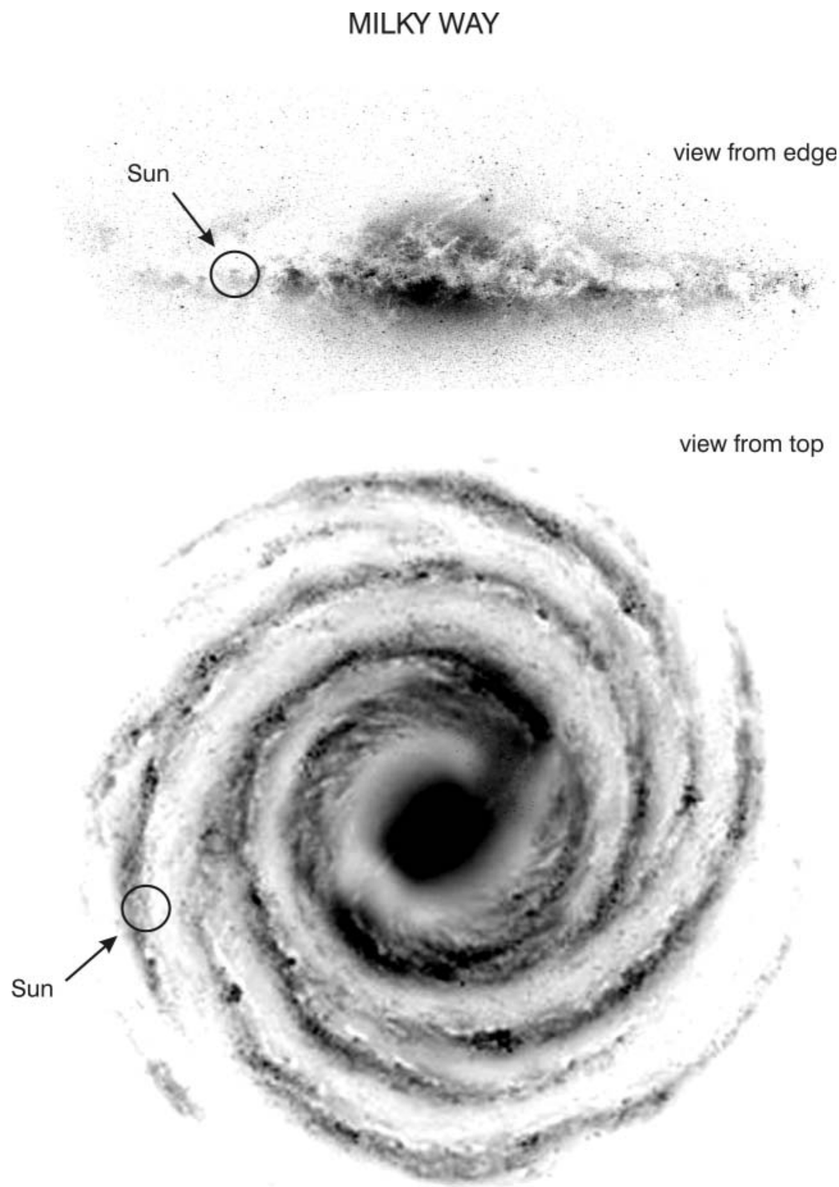


Figure B1. Two views of the Milky Way: Top View and Edge View.

flat, spiral shape structure with a massive cluster of stars at its center and with stars dispersed outward on its spiral arms.

Baade is also credited with discovering two minor planets (more likely **asteroids** than planets) that follow very elliptical orbits. One extends from the asteroid belt (between Mars and Jupiter) to beyond Saturn. He named it Hidalgo, which is Spanish for a person of noble birth. The other he named Icarus after a character in Greek mythology. The "planetoid" Icarus has an elliptical orbit inside Mercury's orbit and sweeps past Earth.

See also Zuckerandl

BABBAGE'S THEORY OF COMPUTING: Mathematics: *Charles Babbage* (c.1791–1871), England.

> *A machine can be built to calculate a series of values of polynomial functions automatically by using finite differences.*

Charles Babbage's birth date is uncertain. It was either the 26th of December 1791 or January 6, 1792. His father was a banker in London who had the means to send him to a private academy and then to continue his education with an Oxford tutor. In 1810 he entered Trinity College in Cambridge. Babbage became familiar with the works of several scientists/mathematicians, including Liebniz's and Newton's calculus. He helped form the Analytical Society whose purpose was to study abstract algebra and improve mathematics in Great Britain. He also helped found the Royal Astronomical Society in Great Britain.

Charles Babbage, known as the father of computing, is also credited with inventing the first ophthalmoscope in 1847, although another inventor in Germany, Hermann von Helmholtz, was unaware of Babbage's instrument and designed his own version in 1850. Babbage gave his ophthalmoscope to a physician to test, but it was neglected for a number of years until later revisions and improvements resulted in the modern instrument that is used to examine the retina, optic nerve, optic disc, and blood vessels of the eye.

Astronomers and mathematicians used other people, usually women, called "computers" to do the complicated calculations involved in their theoretical work, despite the fact that inaccuracies often beset some of their calculations. Thus, Babbage was inspired to develop a machine that could perform complex mathematical computations without errors. In 1822 he outlined his first plan for a "difference engine" that is the forerunner of today's modern computer. It was designed to more accurately calculate star tables to improve navigation. Because of its potential of saving lives at sea, the British government was interested and helped fund Babbage's research. This was most unusual because, in those days, governments did not fund scientific research. However, the promise that his difference engine would improve navigation was a "selling point." Babbage's first attempt was more complicated than he expected. He suffered a nervous breakdown in 1827, the year in which his wife, two sons, and his father died. He ceased work on the project in 1833. Some years later, when he still had no success, the government, as governments are bound to do, stopped funding his research. Although the cessation of funding by the British government effectively ended the practical application of the Babbage "computer," the fact that he could not afford to build the actual machine exclusively with his own funds did not end the theoretical nature of his work. Beginning in 1833, Babbage worked on a different concept that he called an "analytical engine" for which he is more famous. It was based on the system of punch cards used in looms that wove fabrics. Babbage believed instructions could be built into these cards for the loom operators to follow to design the final product. The famous IBM punch card computer of the mid-twentieth century used a similar system.

Babbage started construction on his difference engine in 1823. It is still in existence. In 1991 a working model number 2 was built from Babbage's drawings of his original model. The "first difference engine" stood 8 feet high, had 25,000 parts, and weighed 15 tons. Today, the model can be seen in London's Science Museum. Babbage also designed a printer that could be used with his engine computer that had many features of modern computer printers.

See also Turing

BABINET'S PRINCIPLE: Physics: *Jacques Babinet* (1794–1872), France.

Babinet's principle, sometimes referred to as "Babinet's theorem," states: *The diffraction pattern from an opaque body is identical to that from a hole of the same size and shape as the opaque body except for the intensity of the diffracting light beam.*

Babinet's principle/theorem is true for light and all other types of electromagnetic radiation and is used to detect the relative sameness of size and shape of materials and objects. Although this theorem is most often used in the field of optics, it holds true for all waves of the electromagnetic spectrum. It finds practical uses in determining the equivalence in the size and shapes of objects. For example, by shining a laser light beam through a small blob of blood cells, the diffraction patterns can be used to determine the size of all the blood cells. Another example is the corona or ring-like haze observed around the moon that is caused by sunlight, and which is reflected from the moon's surface, being diffracted by either clouds or water droplets in the earth's atmosphere. This effect is measured by the intensity of the diffraction pattern of the beams of moonlight entering the earth's atmosphere.

Interested in optics and polarization, Babinet developed several instruments and techniques to measure the properties of rocks and minerals, as well as the optical nature of metrological phenomena. He was the first to measure the polarization of light and the nature of rainbows. He was educated at the École Polytechnique and later in 1812 at the Military School in Metz. In 1820 he became a professor at the College Louis le Grand and in 1840 was elected to the French Academy of Sciences. Throughout his life he had varied interests in the optical nature of minerals, polarization of light, meteorology, magnetism, geography, and cartography. He designed and invented several instruments including the *Babinet compensator* and the *polariscope* that are used to polarize light for microscopes. He also invented the *goniometer* used to measure refractive indices.

He is best known for his standardization of the Ångström unit of light as the wavelength of light emitted by heated red cadmium. He suggested that a particular wavelength of light could be used as a standard to measure length. In 1960 his idea was accepted and was used as a definition for the length of the meter. This standard for the meter was the length equal to 1,650,763.73 times the wavelength of orange light emitted by the gas of the pure isotope krypton-86 when the gas is excited by an electrical discharge. The krypton-86 wavelength standard for the meter was changed in 1983 to equal the fraction 1/299,792,458 that light travels in one second.

BABO'S LAW: Chemistry: *Lambert Heinrich Clemens von Babo* (1818–1899), Germany.

> *The vapor pressure over a liquid decreases proportionally when specific amounts of solute are dissolved in the liquid.*

This was the first quantitative measurement that stated that the vapor pressure of a liquid is decreased proportionally to the amount of solvent added to the liquid, when the liquid's temperature is unchanged.

In 1845 Lambert von Babo was appointed to an assistant professorship at the University of Freiburg in Germany and later advanced to a full professor in 1859. Babo was one of the earliest chemists to do quantitative studies of vapor pressures over water. As a chemist he was aware of works of Charles Blagden (1748–1820), the British physician and scientist, who in 1788 observed that adding a solute to a solvent lowered the freezing point of the solution, as well as that of Michael Faraday who in 1822 determined that adding a solute to a liquid raised the solution's boiling point. In 1882 the French physical chemist François Marie Raoult performed more quantifiable experiments to show how solutes that affect the freezing points of a solution might be used to determine molecular weights. All of these chemists were familiar with Robert Boyle's research that established the relationship between temperature, pressure, and volume of gases.

See also Raoult

BACON'S CONCEPT OF INDUCTIVE REASONING: Philosophy of Science: *Francis Bacon,* 1st Baron Verulam, Viscount St. Albans (1561–1626), England.

Francis Bacon was a philosopher/scientist, politician, and writer, whose book *Novum Organum,* published in 1620, has influenced every scientist since his day by introducing the logic of induction and devising his "scientific method," which in essence proceeds from the specific to the general:

1. *Approach* the problem without prejudices; proceed with inquiry.
2. *Observe* situations accurately and critically.
3. *Collect* relevant facts and data from observations; make measurements.
4. *Infer* by use of analogies based on characteristics of observed facts.
5. *Draw* general conclusions from the specific to the general.
6. *Correct* initial conclusions with new insights. Truth comes from error, not confusion.

Francis Bacon started his career at the age of 12 when he entered Trinity College, Cambridge, although he never graduated. He then pursued a career in law in 1576 and was first elected to the House of Commons of Parliament in 1584. He continued his career as a statesman and was knighted 1603. In rapid succession he became the attorney general in 1613 and was proclaimed a Baron in 1618 and the Viscount St Albans in 1621. But all this ended in the same year he became Viscount when he was removed from office after being convicted of accepting bribes. He was removed from Parliament, fined, and sent to prison. In 1621 King James I pardoned him, but he was not allowed to return to Parliament. (King James I was actually the Scottish King James VI who succeeded the unmarried, childless English Queen Elizabeth I upon her death in 1603.) This crime was unfortunate for his political career but was fortunate for science as the rest of his life, although short, was devoted to efforts related to the philosophy of science.

His early philosophy was concerned with purging the mind of what he called "idols" that are the tendency of humans to believe in things that are not true (errors). (This seems to be as true today as in the 1600s.) His intention was to write a six-volume work called *Instauratio Magna* (Great Restoration) that included 1) a way to classify science, 2) his new inductive science, 3) a listing of facts acquired by experimentation, 4) how to use new approaches to learning, 5) general facts learned from natural history, and 6) his final philosophy of the science of nature. However he completed just two parts of this massive project: *The Advancement of Learning* in 1605, which was a review of the state of knowledge in England at that time in history and which was expanded in Latin as *De Augmentis Scientarum* in 1623, and *Novum Organum* (Indications Respecting the Interpretation of Nature) which was published 1n 1620—the year before his removal from Parliament.

Although Bacon is not considered a great experimental scientist, his philosophy of science, best known for his inductive method of investigation nature (scientific method) was appreciated by later scientists, such as Robert Boyle, Sir Isaac Newton, Voltaire, Robert Hooke, and many others who considered him the father of modern science.

His *inductive method* was a great improvement over the Aristotelian *deductive method* (that proceeds from the general to the specific) and the *philosophical thought* processes many ancients used to arrive at conclusions. (Bacon disagreed with Aristotle's philosophy that was based on "truth is derived from authority," and he believed that Arisotelianism produced only disputes.) Bacon's inductive reasoning improved the way scientists observed and experimented and thus arrived at a more authentic or "factual" understanding of nature. It also improved the process of establishing scientific hypotheses that could lead to new theories, principles, and laws of nature while still leaving room for future corrections. Of great importance was his idea of generating tentative conclusions such as hypotheses and theories that could be addressed and corrected by further scientific investigations.

Bacon was the first to observe that the coastlines on both sides of the Atlantic Ocean (Europe/Africa and North/South America) seemed to fit each other. Years later, this concept was developed into the theory of continental drift by Suess and Wegener.

See also Boyle; Ewing; Hess; Hooke; Newton; Suess; Wegener

BAEKELAND'S CONCEPT OF SYNTHETIC POLYMERIZATION: Chemistry: *Leo Hendrik Baekeland* (1863–1944), Belgium and the United States.

Leo Hendrik Baekeland started his career as a professor of physics and chemistry at the University of Bruges in Belgium in 1887 and later returned to University of Ghent where he received his doctorate. On his honeymoon in 1889 in the United States he realized that this was the place to begin a career as an industrial chemist. More of an entrepreneur than an academic professor, Baekeland started a consulting laboratory to explore possibilities in the field of photography. His first success was the invention of paper called Velox that was coated with light sensitive salts that could be used to produce positive photographs from the projection of the image from a negative of the image. It became a well-known product that he sold in 1899 to George Eastman of the Kodak Company for $1 million. These funds provided independence enabling him to investigate a new field of chemistry known as polymerization.

Baekeland began with experiments to find a substitute for shellac that at the time was manufactured by collecting a natural resin secreted by an oriental beetle that deposited this secretion on twigs of trees in India.

As a chemical reaction, polymerization requires that small molecules that make up larger molecules have at least two points involved in the reaction. The reaction usually requires a catalyst and heat, and often light and pressure, to force the smaller molecules to combine into larger chain-like macromolecules called monomers. There are two major types of polymerization. One, known as *condensation polymerization,* takes place when the growing chain eliminates some of the smaller molecules such as H_2O and CH_3OH. The other is called *additional polymerization* in which the polymer is formed without the loss of other chemicals. Polymerization can occur in nature, but today there are many known polymerization chemical processes used to make synthetic versions of what we now know as plastics.

After collecting the resin, and then undergoing a process of cleaning and purifying, it was formed into thin sheets. When broken into flakes, it was called "orange shellac." Natural shellac is soluble in alcohol but not water and is used as an undercoating on wood before varnish is applied. Because it is a "natural" product, shellac's source and availability was limited. This inspired Baekeland to find a synthetic substitute, although his motives were less than altruistic, as he openly admitted his main goal was to make money. Many scientists by patenting their discoveries have a motive to make money, which in a democracy is considered moral if the goal is to provide a useful product.

As an experimental chemist, he combined the synthetic phenol/formaldehyde resin-like substance that was first produced by Johann Friedrich Adolph von Baeyer in 1871 but had no success. By adding some other ingredients, including wood flour filler, as well as applying heat and pressure, he produced the first synthetic plastic, Bakelite in 1909. It was named after him. Soon after, Baekeland founded the General Bakelite Company that merged with two rivals, the Condensite Corporation and the Redmanol Company in 1922. In 1939, the Bakelite Corporation, the new name, was acquired by Union Carbide and Carbon Corporation.

Bakelite can be formed in molds, machined, and produced in many forms. One of its essential properties is its electrical insulation capability. As the first totally synthetic plastic, Bakelite was used in the manufacture of a variety of toys, kitchenware, telephones, and other electrical related equipment. The complexity and high cost of its production, along with its brittleness and other undesirable qualities, proved its undoing when other superior plastics were able to be produced. Bakelite was soon replaced by other polymer plastics.

Leo Hendrik Baekeland served as president of the American Chemical Society in 1924 and continued producing scientific papers until his death in 1944.

BAER'S LAWS OF EMBRYONIC DEVELOPMENT: Biology: *Karl von Baer* (1792–1876), Germany and Russia.

> *Individuals develop by structural elaboration of the unstructured egg rather than by a simple enlargement of a preformed entity*. This theory, also referred to as *epigenesis*, is based on Baer's four rules formulated in 1828:

1. In a large group, the *general* characteristics of animals will appear early in their embryonic development, whereas more *special* differences will appear later in their development.
2. The *more general* structural forms are formed before the *less general* structural forms are developed. Both forms are followed by the development of the *most specific* structural forms.
3. The more an embryo of a given animal becomes specialized, the more different it becomes from other species of animals as it matures.
4. Therefore, the embryos of higher animals only resemble other animal forms in the embryo stage.

This theory is basic to the field of embryology and, in essence, states that mammal development proceeds from simple (general) to complex (specific)—from homogeneous to heterogeneous. This means that, though all mammal embryos may look similar and have similar rudimentary structures, they grow up to be very distinctly different adult species. Baer's theory made the *recapitulation* theory impossible because young embryos are undifferentiated in form and are not previous adult ancestors. This means that mammals of a higher form of animal never resemble any other form of animal, except in the embryo stage. In other words, animal development proceeds from the general to the more specific. As the embryo matures into a fetus and later grows into an adult changes are not only differentiated but also irreversible.

Although of German descent, Karl von Baer was born in Estonia, where he studied and graduated with a degree in medicine in 1814. However, he was dissatisfied with his medical training and moved to Germany and then Austria for more advanced studies from 1814 to 1817. Beginning in 1817 Baer taught at the University of Königsberg (present-day Kaliningrad) in Russia where in 1826, while studying follicles and eggs (ovum) of mammalian ovaries, he identified the ovum as developing into an embryo. He continued the studies of other biologists in this area and is now known as the father of comparative and descriptive embryology. Baer also corrected some of the misconceptions of the mechanistic view of mammalian development from embryo to fetus to adult. The common belief of many biologists of his day and before, even as far back as Aristotle, was the embryos of one species pass through comparable stages to adults of other species. This was known as "recapitulation theory," or as "ontogeny follows phylogeny," and also as Haeckel's "biogenetics law." These theories all state that the embryos of one species pass through stages comparable to adults of other species.

See also Gould; Haeckel; Russell

In addition to embryology Karl von Baer had other interests. He teamed up with Jacques Babinet, a French physicist, to study factors that influence the directional flow of rivers, as well as currents in other bodies of water. This law is known as the ''Baer–Babinet law of current flow.'' The directional flow of rivers, as well as ocean currents such as the Gulf Stream, are affected by the results of tectonics (movement of continental plates) and the Coriolis force created by the rotation of Earth. Tectonic movements of large plates of Earth have altered land structures and influenced the currents of rivers, lakes, and oceans by uplifting some regions as one giant plate overrode another plate. This geological activity creates an uplift of the lithosphere (Earth's crust) in some areas while submerging other regions, causing water to flow from the higher uplifted areas to the lower submerged region. The other force that affects direction of water flow is related to the physical law of ''conservation of angular momentum'' that is exhibited by the rotation of Earth on its axis. A river flowing northward will be diverted to the east due to the Coriolis force, whereas a stream flowing southward will be directed to the west. This effect is responsible for the direction of flow of the Gulf Stream northeastward toward Great Britain, and the counterclockwise direction of winds in hurricanes heading out of the South Atlantic Ocean to the north along the East Coast of the United States. *See also* Babinet; Coriolis; Wegener

BAEYER'S STRAIN THEORY FOR COMPOUND STABILITY: Chemistry: *Johann Friedrich Adolph von Baeyer* (1835–1917), Germany. He was awarded the 1905 Nobel Prize in Chemistry for his work on organic dyes and hydroaromatic compounds.

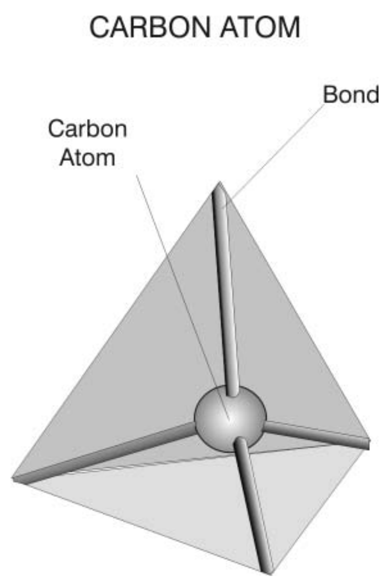


Figure B2. Tetrahedron structure of carbon atom.

After twelve years as a successful teacher of organic chemistry in several schools, Adolph von Baeyer moved to Munich where he spent the rest of his life working on the organic chemistry of dyes. He discovered phthalein dyes, phenolphthalein, and fluorescein as well as a phenol-like formaldehyde resin that was further commercially developed by Leo Baekeland as Bakelite (*see* Baekeland).

Baeyer is best known for his synthetic development of a synthetic indigo dye begun in 1865. Indigo dye known for its distinctive blue color has an interesting history. It is one of the oldest dyes used to color textiles and in paintings and has been used for hundreds of years in Asia and India. It was even known in ancient Greece, Rome, and the Middle East. India was the major supplier of indigo to Europe during the occupation by Roman troops and into the Middle Ages.

Indigo dye originates in several plants including the woad (*Isatis tinctoria*), the dyers' knotweed (*Polygonum tinctorum*), the true indigo plant in Asia (*Indigofera tinctoria*), plus several other varieties from Asia, Central, and South America. Native plants that were used to produce indigo, particularly in India during the 1800s were replaced by the synthetic versions produced in the late 1800s and early 1900s. The development and production of synthetic dyes devastated the indigo business in many countries. In modern times, over 17,000 tons of synthetic indigo dyes are produced in several countries.

Indigo dye is not only used to dye blue jeans. (Cloth dyed with indigo fades when repeatedly washed because indigo is not a "fast" dye. This quality seems to make clothing dyed with indigo more desirable to young people.) It is also used as a food coloring known as Blue No. 2.

The original synthetic indigo dye Baeyer developed was too expensive for commercialization; but later other similar chemical compounds were synthesized, and by 1890 they became inexpensive and thus commercially successful. Baeyer also worked on hydrobenzenes, terpenes, organic explosives, uric acid, and synthesized barbiturate drugs. There are several tales about how he came to the term "barbiturate." One involves it being named after a lady friend of his, Barbara. Another is that he celebrated his discovery on the feast of St. Barbara. Although interesting, both are unproven.

> *Chemical compounds (molecules) are less stable the more they depart from a regular tetrahedral structure.*

A regular tetrahedron is a four-sided (faces) polyhedron. Each face is a triangle. It has four verticals and six line segments that join each pair of verticals. It may also be described as an analog of a three-dimensional triangle. This is the typical structure for some crystals and carbon **compounds**, where the carbon atom provides a **covalent bond** to each of the four corners of the tetrahedral atom to other elements (see Figure B2 tetrahedron, and Figure V3 carbon atom under Van't Hoff.) Think of the tetrahedron structure of the carbon atom as having one electron at each of the four corners. Each of these electrons can be shared with the outer electrons of other carbon atoms and atoms of other elements to form a wide variety of structures, such as long chains of carbon atoms with branches or rings whose "skeleton" is formed by connecting carbon bonds. This unique tetrahedron structure for carbon makes it important for the formation of the many different types of organic molecules that make up plants and animals.

See also Kekule; Van der Waals; Van't Hoff

BAHCALL'S THEORY FOR THE SOLAR NEUTRINO MODEL: Astronomy: *John Norris Bahcall* (1934–2005), United States.

> *The sun produces 10^{36} neutrino events every second (solar neutrino units of SNU) at a density (flux) of 8 SNU.*

A **neutrino** is an elementary particle classed as a **lepton** (somewhat like an electron of the same class) that has zero mass at rest as well as a zero electrical charge. It has other characteristics that make it useful for studying other minute particles produced in accelerators. The sun's interior is a natural nuclear fusion (atomic) reactor that produces its energy by the proton-to-neutron chain reaction by converting four protons (hydrogen nuclei) into helium, neutrinos, and other forms of energy such as gamma rays as well as the kinetic energy of the neutrinos and other moving particles that travel from the interior of the sun to the earth. The solar neutrino model presents several problems related to the number and types of emissions of neutrinos from the sun. John Bahcall and several other theorists predicted that neutrinos, which are considered weightless, will strike the earth and not be absorbed, as are some of the other heavier particles created by the fusion reaction that takes place in the sun. His theory was tested by others but did not seem to hold up very well. This prompted Bahcall to consider several options to his theory. One was that the sun was going through a passive phase and that only over a long period of time (cycles) would his predictions be accurate. Another consideration was that the neutrinos were decaying before they reached Earth, thus causing a lower count than his predictions. Still another consideration was that perhaps the entire solar neutrino model was wrong, which caused a false count in his predicted neutrino rate and density. The problem is still not settled and is now left up to the development of better instrumentation or revised and improved theories to account for the extent of neutrino production by the sun. More recent speculation involves the vast amounts of dark matter (over 90% of all matter in space) that may be composed of neutrinos left over from the big bang. It is now estimated that one type of neutrino, called the *electron neutrino*, is not exactly massless but has a tiny mass of about 0.5 eV to 5.0 eV, which is less than 1 millionth the mass of a regular electron.

Until improved equipment is developed and additional and improved data is acquired relating to the neutrino problem, it will remain speculation and a problem for future theoretical physicists and cosmologists to solve.

See also Bethe; Birkeland; Fermi; Pauli

BAKKER'S DINOSAUR THEORY: Biology: *Robert Bakker* (1945–), United States.

Dinosaurs were warm-blooded, similar to mammals and birds, and were not related to cold-blooded reptiles.

Robert Bakker based his theory of warm-blooded dinosaurs on the following evidence: 1) Bones of warm-blooded animals, such as mammals and birds (including some dinosaurs), have blood vessels, whereas cold-blooded reptiles' bones exhibit growth rings. Other bone structures also suggest that at least some dinosaurs were warm-blooded. 2) The fossil of a dinosaur heart with four chambers was found that indicates that at least some species were warm-blooded. Other fossilized dinosaur hearts were chambered—similar to reptiles. 3) Cold-blooded animals cannot withstand large variations in climate, such as the cold northern parts of the United States and Canada. Cold-blooded animals are *ectothermic*, which means their bodies cannot self-adjust internal temperatures to react to external temperatures. They do not have an internal thermostatic system to control their internal temperature, thus they need less food and less sleep. Because dinosaur fossils have been found in cold northern climates, it seems that they were *endothermic*. Although warm-blooded animals are endothermic and do have internal thermostatic systems, they need more food and sleep; and 4) warm-blooded animals have a high rate of metabolism. Therefore the *prey ratio* is much higher for warm-blooded mammals than reptiles—that is, the food consumption for warm-blooded animals is many times higher (per unit of body weight) than it is for cold-blooded reptiles. Fossil evidence suggests dinosaurs consumed vast amounts of plant and animal foods.

From these data, Bakker, as well as some others, concluded that, at least, some species of dinosaurs were more closely related to birds than reptiles, both having a common fossil ancestor known as *thecodonts* that means "animals with teeth embedded in the jaws." Bakker's theory created much discussion in the field of paleontology and raised concerns about some of the concepts of evolution. (He is a Pentecostal preacher and a proponent of theistic evolution.) Not all scientists agree that dinosaurs were warm-blooded. His theory is still being debated.

BALMER SERIES: Mathematics and Physics: *Johann Jakob Balmer* (1825–1898), Switzerland.

The Balmer series is the designation of a set of Balmer lines that are lines in the hydrogen spectrum that are produced by changes between $n = 2$ and levels greater than *2* either in emission or in absorption, where *n* represents the principal quantum number.

Johann Jakob Balmer was born in Switzerland, attending universities in Switzerland and Germany. He received his degree in mathematics from the University of Basel in 1849 and lived there the rest of his life. He began his career teaching in a girls' school and did not make any real contributions to the field of mathematics until the age of 60. In 1885 he devised a rather simple formula that described the wavelength for hydrogen's spectral line. This led to a generalized concept for the Balmer lines and the Balmer series. The formula was limited to the spectral lines of the hydrogen atom but later was expanded to include the spectral lines for all elements.

$$\text{Balmer's formula is: } \lambda = \frac{\mathfrak{h} m^2}{(m^2 - n^2)}$$

Where λ = the wavelength. $\mathfrak{h}$ = a constant with the value of 3.6456×10^{-7} meters, or 364.56 nanometers, $n = 2$, and m = an integer when m is greater than n.

Balmer devised the formula by gathering empirical evidence and thus was unable to explain why his formula was correct. (This was due to his and other scientists' lack of knowledge about the structure of the atom at that time in history.) It was later in 1888 when Johannes Rydberg generalized Balmer's formula so that it can be used for all transitions for the hydrogen atom. The four main transitions of hydrogen are based on the principle quantum numbers of the electron in the hydrogen atom. The wavelength and Greek letter associated with the different colors of the electromagnetic spectrum are:

$\lambda = \alpha$ at 656 nm, red color emitted
$\lambda = \beta$ at 486 nm, blue-green color emitted
$\lambda = \gamma$ at 434 nm, violet color emitted
$\lambda = \delta$ at 410 nm, deep violet color emitted.

The Balmer series is important in the field of astronomy because it shows up in many stars due to the abundance of hydrogen in the universe and stars. Starlight can show up as absorption or emission lines in the spectrum depending on the age of the star. Thus, the Balmer series assists in determining the age of stars because younger stars are mostly hydrogen whereas older stars have used up much of their hydrogen due to the fusion process and end up with a higher proportion of heavier elements, thus they are not as bright.

BALTIMORE'S HYPOTHESIS FOR THE REVERSE TRANSFER OF RNA TO DNA: Biology: *David Baltimore* (1938–), United States. David Baltimore, Howard Martin Temin, and Renato Dulbecco jointly received the 1975 Nobel Prize for Physiology or Medicine.

> *A special enzyme, called reverse transcriptase, will reverse the transfer of genetic information from RNA back to DNA, causing the DNA possibly to provide information to protect cells.*

Previous work with **DNA** and **RNA** indicated that genetic information could be passed from DNA to RNA but not the other way around. David Baltimore and Howard Temin independently announced that the enzyme reverse transcriptase enabled RNA to pass some genetic information to DNA, which possibly could aid cells to fight off cancer and other diseases, such as HIV/AIDS.

Baltimore also worked on the replication of the poliovirus and continues research on the HIV **retrovirus**, which was identified by other biologists. Baltimore and other virologists hope their research will lead to a better understanding of the relationship between the HIV retrovirus and AIDS. Biomedical researchers are attempting to find an effective vaccine that will prevent the damage the HIV virus does to the immune system or prevent AIDS by immunization.

See also Dulbecco; Gallo; Montagnier; Temin

> David Baltimore has had a varied career between academic administration and academic research. After studying chemistry at Swarthmore College, and later attending Massachusetts Institute of Technology (MIT) and the Rockefeller University, he changed his field to virology. It was as director of the Whitehead Institute in Cambridge, Massachusetts, that he began his groundbreaking research on DNA and RNA. In 1970 he presented his discovery of the new enzyme ''reverse transcriptase'' that can transcribe RNA information into DNA in some cancer viruses. This was a unique discovery because, up to this time, it was assumed that the transfer of information could only be by DNA.
>
> Baltimore became president of the Rockefeller University in 1990 where he played an unusual role as university presidents go by combining the careers of administrator, researcher, and fund-raiser. A colleague was accused of falsifying data after submitting a research paper to the magazine *Cell* with Baltimore as a coauthor. As the case developed over a period of years, it became an excellent example of what can happen when politics becomes involved in science. The investigation affected several careers over the years. Baltimore admitted his involvement, removed his name from the paper, and apologized. The researcher was later vindicated of fraud. As a result of the charges of falsifying data, Baltimore's position became difficult resulting in his resignation as president of the Rockefeller University. He returned to MIT in 1994 and in 1997 he became president of the California Institute of Technology where he became appreciative of the great advances being made in all areas of science. He resigned in 2006 after nine years as president of California Institute of Technology. It seems that about ten years is the average tenure of college presidents.

BANACH'S THEORY OF TOPOLOGICAL VECTOR SPACES: Mathematics: *Stefan Banach* (1892–1945), Poland.

> *Banach vector spaces are complete normed vector spaces where the space is a vector space* V *over a real or complex number and the norm introduces topology onto the vector space.*

Banach's most important work was in function analysis where he integrated related concepts into a comprehensive system of normal linear spaces, which became known as Banach spaces—a type of vector space. In 1924 he and Alfred Tarski (1902–1983) jointly published their theory of "The Banach–Tarski paradox" where they claim that it is possible to dissect a sphere into a finite number of pieces (more than five), which mathematically can be recombined to form two spheres the same size as the original sphere. Banach's major work was published in *Theory of Linear Operations* in 1932. In addition to founding the modern theory of functional analysis, he made contributions to the theories of topological vector spaces, measure theory, integration, and the orthogonal series. In 1979 a two-volume commentary of his works was published.

Stefan Banach was given his mother's surname but never saw her after his birth. His father, Stefan Greczek, gave him his first name, but, because of financial and social circumstances, Banach was raised by another family. Stefan Banach's father contributed to his financial support and maintained a relationship with his illegitimate son. From 1910 to 1914 Banach worked his way through Lvov (or Lwow) Technical University (now the Ivan Franko National University of Lviv in the Ukraine). He taught mathematics in local schools and in 1922 was hired by Lvov University where he did most of his research before dying of lung cancer in 1945.

BANTING'S THEORY FOR ISOLATING PANCREATIC INSULIN: Medicine: *Sir Frederick Grant Banting* (1891–1941), Canada. Frederick Banting was awarded the 1923 Nobel Prize in Physiology or Medicine along with his coresearcher, J. J. Macleod.

> *By ligating the pancreatic duct, it is possible to extract the polypeptide hormone insulin from the islands of Langerhans within the pancreas before the destruction of insulin can take place. The extracted insulin can therefore be administered to a diabetic patient in an effort to regulate carbohydrate metabolism within the body.*

Trysin-secreting cells are produced in the pancreas. When insulin that is produced in the pancreas is destroyed by proteolytic enzymes, the body is unable to metabolize carbohydrates (sugars) correctly. The result is a condition called diabetes.

Frederick Banting was born on a farm in Alliston, Ontario, Canada, where in 1910 he entered Victoria College at the University of Toronto to become a medical missionary. He received his medical degree in 1916 and entered the Canadian Army Medical Corps during World War I. In 1918 he received the Military Cross for heroism after being wounded in the Battle of Cambria in France. After the war he set up a practice related to children's diseases but soon joined the University of Western Ontario at London, Ontario, to specialize in research related to pancreatic cells known as "islets of Langerhans" that were, in some way, related to regulation of sugar metabolism and diabetes.

With the assistance of a professor of physiology, the Scottish physician John Macleod (1876–1935), and a young research assistant, Charles Best (1899–1978) an American physiologist who was educated in Canada, Banting performed a series of crucial experiments in a borrowed laboratory. They tied off the pancreatic ducts of dogs and took samples of the insulin extracted from the islets of Langerhans that was now isolated from other secretions, namely trypsin. They then injected these insulin extracts into diabetic dogs and found that they had some beneficial effects protecting the dogs from diabetes. The trio asked James Collip (1892–1965), a Canadian biochemist, to purify the extract. Soon after, the four of them (Banting, Macleod, Best, and Collip) patented the hormone. It is now known as insulin. They licensed it to Eli Lilly, receiving a royalty that was used to support their research.

It should be noted that at the time of Banting's "discovery," insulin was already identified and named. In 1916 an English physician, Sir Edward A. Sharpey-Schafer (1850–1935) formulated the word "insulin" after theorizing that a single substance produced in the islands of Langerhans in the pancreas is responsible for the condition called diabetes mellitus. Also, a Romanian professor, Nicolae Paulescu (1869–1931), isolated insulin in his lab about a year before the Canadians. He called it pancreatine. However, he only published his findings in French and was never accorded any real recognition for his efforts.

In 1923 the Nobel Prize was awarded to Banting and Macleod, but not to the other two researchers. This infuriated Banting and Macleod who then shared their prize money with Best and Collip. Macleod was Banting's lab supervisor and did little of the actual work involved in this important discovery. Banting was knighted in 1934 and worked with the Canadian and British medical research efforts dealing mainly with the effects of mustard gas and the physiological problems of fighter pilots. In 1941 he died in an airplane crash on his way to England to continue his research.

After eating, carbohydrates and sugars are absorbed by the intestines and then into the bloodstream and finally into the cells. Insulin is secreted by the pancreas as a response to an increase of blood sugar in the system. Cells have insulin receptors with the capacity to bind and absorb the blood sugar (glucose) from the blood into the cell where it is used in the process of metabolism to produce energy. If an individual's body is unable to produce adequate insulin or the cells cannot receive insulin, no matter how much an individual eats, he or she can still "starve." This is why victims of type 1 diabetes become very ill without insulin shots. Whereas, people with type 2 diabetes have developed a resistance to insulin rather than a deficiency of insulin. Type 2 diabetes patients do not respond well to insulin because their cells cannot absorb the sugar from the blood, leading to sugar levels in the blood that are higher than normal. The first insulin used by humans to treat diabetes was purified insulin extracted from cows and later pigs. This nonhuman insulin works well with most people, but some individuals develop allergies and other reactions to animal insulin. By the 1980s researchers developed a method to produce human insulin by using recombinant DNA techniques where the human gene that codes for insulin was copied and then placed inside bacteria. The gene is then "tricked," the end result being the bacteria cells make human insulin constantly. Because all humans have the same insulin genes, sensitive people are not allergic to it nor are humans as likely to reject this "biologically engineered" insulin. Medical research continues to seek a cure for diabetes. Some researchers believe that stem cells may play an important role in this endeavor. In the meantime, there are multiple new drugs on the market that are effective in controlling blood sugar levels in diabetes patients.

BARDEEN'S THEORY OF SUPERCONDUCTIVITY: Physics: *John Bardeen* (1908–1991), United States. John Bardeen is the only person to receive two Nobel Prizes for Physics. In 1956 John Bardeen, Walter Brattain, and William Shockley received the Nobel Prize for the development of the point contact transistor. And in 1972 he shared the Nobel Prize for Physics with Leon Cooper and John Schrieffer for developing the BCS theory of superconductivity.

When electrons interact in pairs in a vibrating crystal lattice, the electrons will cause a slight increase in positive charges in the crystal creating binding energy that holds *the electron pair together, except at very low temperatures (near absolute zero), and thus not exhibit electrical resistance.*

After graduating from high school at age 15 Bardeen attended the University of Wisconsin where he graduated in 1928, receiving his bachelor's and master's degrees in electrical engineering at that time. He secured a position at Gulf Research Laboratories in Pittsburgh. While there, he helped develop magnetic and geophysical means for oil prospecting, but he decided his interests were really in theoretical physics. He also spent five productive years with Bell Labs in New Jersey, working in the field of solid-state physics. While there, he and his colleagues, Walter Brattain and William Shockley, developed the **transistor**.

Influenced by other outstanding professors and researchers, Bardeen conducted research on the electrical conductivity of metals. After graduating from Princeton in 1936 with a PhD in mathematical physics, he went on to wartime research at the Naval Ordnance Laboratory in Washington, D.C. In 1951 he became professor of electrical engineering and physics at the University of Illinois in Urbana.

Beginning in 1945 his main research interests were in the theoretical effects of quantum mechanics as related to electrical conductivity in semiconductors and metals, which led to the invention of the transistor. In cooperation with two colleagues, Leon Cooper and John Schfieffer, they developed a viable theory of superconductivity, at low and "high" temperatures that is also known as the BCS theory of condensed matter or superconductivity.

John Bardeen's work with transistors and the theory of superconductivity of metals revolutionized electronics. Transistors are a necessity in our modern world. They are used in radio and television transmitting and receiving equipment, telephones, computers, and wherever electrical distribution systems are in place, such as automobiles, airplanes, ships, security systems, and so forth.

BARRINGER'S IMPACT THEORY OF CRATERS: Geology: *Daniel Moreau Barringer* (1860–1929), United States.

Craters were formed on the planets (including Earth) and the moon by the impact of large extraterrestrial objects such as meteors, asteroids, and comets.

Following is the evidence that Barringer developed for his theory:

1. The large amount of silica powder found at crater sites could be formed only by very great pressure.
2. In the past, large deposits of meteoritic iron "globs" were found at the rims of craters, most of which was removed many years ago by humans.
3. Rocks from deep in the craters are mixed with meteoritic material.
4. There is no evidence of volcanoes at crater sites. Therefore, they could be ruled out as a possible cause of impact craters.

Barringer's impact theory for craters is based on his study of the famous meteor crater (also referred to as the Barringer meteorite crater) located near Flagstaff, Arizona. Estimated to be twenty thousand to twenty-five thousand years old, it is almost 1 mile across and 600 feet deep. Compared to other meteorite impact craters, it is considered small.

Barringer was not the first to study this crater or come up with theories of crater formation on Earth. He did, however, establish the impact theory for craters, which is generally accepted within the scientific community. He did this despite having at one time agreed mistakenly with the theory that the meteor crater was the result of the impact of a meteor of the same size as the crater itself. (The current estimation of the size of the meteorite that impacted to create the Barringer crater is about 35 feet in diameter. It was a very dense iron meteorite weighing about 10,000 tons.) After Barringer found small pieces of nickel-iron rocks in the area, he spent a great deal of money establishing a mining company to extract the meteorite iron thought to be at the bottom of the crater. However, he was unsuccessful in finding significant deposits. Today, his theory is still the best explanation for most craters, including the Barringer meteorite crater found in Arizona. It is believed that at one time Earth's surface was pockmarked with craters, as is the current moon's surface, primarily because the moon does not experience extensive erosion. However, the process of weathering and erosion over eons of time has eliminated most of the evidence of the largest craters on Earth.

BEAUMONT'S THEORY FOR THE ORIGIN OF MOUNTAINS: Geology: *Jean Baptiste Armand Leonce Beaumont, Elie de* (1798–1874), France.

> *Mountains were rapidly formed by the distortion of molten matter as it cooled in the earth's crust.*

Jean Beaumont's theory is an explanation for the formation of mountains consisting mainly of basalt rocks, but not sedimentary shales or layered limestone. His theory is still considered viable by some biologists and geologists, particularly by those who believe in the concept of ***catastrophism***—theories that deal with the different types of catastrophic events on Earth that occurred in the past. These catastrophic events on Earth include earthquakes and volcanoes, which possibly are responsible for the formation of mountains, as well as catastrophic meteor impacts/craters and major climate changes. The major evidence in support of Beaumont's theory is that "roots" of mountains are less dense than the rocks found at the mountains' higher elevations.

Modern theory for the origin of mountains is based on the concept of the earth's crust being raised above the surrounding area by the warping and folding of surface rock into layers. Another modern concept is *plate tectonics*: large plates on the ocean floor and under the continents move and crash into each other over eons. This plate movement, at a depth of 25 to 90 miles, has been ongoing for the past 2.5 to 3 billion years and still continues. The crashing together of the edges of these plates cause the development of earthquake fault lines similar to those located in California, Eastern Europe, and Asia. Plate movement is the process responsible for building the global distribution of mountains, as well as resulting in earthquakes and volcanoes. Mountains are formed in either a ring configuration, as in the Olympic Mountains in Washington State, or, more often, in ridges linked together, as in the Sierra Nevada range. A third type is the group of ranges similar to the Rocky Mountains in the western United States, the Andes in South America, the Alps in Europe, and the Himalayas in Asia. Beaumont's theory, though not completely wrong, is too limited as a geological concept for the origin of mountains.

See also Buffon; Cuvier; Eldredge; Gould

BECQUEREL'S HYPOTHESIS OF X-RAY FLUORESCENCE: Physics: *Antoine Henri Becquerel* (1852–1908), France. Antoine Becquerel shared the 1903 Nobel Prize for Physics with Marie and Pierre Curie.

The exposure of fluorescent crystals to ultraviolet light will produce X-rays.

Antoine Becquerel's concept is an excellent example of how his hypothesis, which proved false, later resulted in a discovery of great importance.

Wilhelm Röentgen discovered X-rays in 1895. Becquerel believed he could produce X-rays by exposing his **fluorescent** crystals (salts) to sunlight (**ultraviolet** radiation). He placed his crystals on a photographic plate covered in black paper and then exposed both to sunlight. His original hypothesis assumed that the photographic plate had been darkened by what he incorrectly thought was exposure to X-rays passing through the paper from the crystals. He inadvertently left an unexposed, wrapped, photographic plate in a desk drawer with some of his fluorescent crystals on top of the plate that had not been exposed to sunlight. To his amazement, when the plate was developed, it was darkened as if it had been exposed to something coming from the crystals—obviously not ultraviolet light, because it was stored in a dark drawer. Because neither the plate nor the crystals were exposed to sunlight, he concluded that his original hypothesis was incorrect. He now hypothesized that the crystals gave off some form of penetrating radiation (later identified as radiation of short wavelengths with an electrical charge such as beta and gamma rays.) He continued to experiment and found that the radiation could be deflected by a magnet and thus must consist of minute charged radiation particles. Becquerel is credited with discovering *radioactivity*.

See also Curies; Röentgen; Rutherford

BEER'S LAW: Physics: *August Beer* (1825–1863), Germany. (Note: This law is also known as the **Beer–Lambert–Bouguer law** because all three independently discovered variations of the law at about the same time.

Their law states: *There is a logarithmic dependence between the transmission of light that shines through a material and the density of the material as well as the length of the material that the light is traveling through.*

In 1729 Pierre Bouguer's theory was published that defined the amount of light that was lost by passing it through a given amount of atmosphere. Pierre Bouguer (1698–1758), a French mathematician, also determined that the sun's light was 300 times brighter than the moonlight reflected from its surface that originates from sunlight. Johann Heinrich Lambert (1728–1777), a German mathematician, physicist and astronomer, published a book in 1760 on how light is reflected from different surfaces. He coined the word "**albedo**" (the reflection factor of light or other forms of radiation from a surface). Lambert also presented a hypothesis that the planets near the sun were part of a system that traveled within the Milky Way galaxy, and that our solar system is just one of many found in the galaxy. He also presented a hypothesis for the nebular (interstellar cloud of gas) origin of our solar system.

In 1852 August Beer expressed his law in several elaborate forms of common logarithms and in exponential equations. In essence, the results may vary according to the ability of the material to absorb light and the material's wavelength. In other words, if the material is very dense or opaque the law does not apply because little or no light can transverse the material. This law is expressed in logarithms when applied to **spectrophotometry.** When used with regular optical equipment, it is expressed in exponential form.

Little is known about August Beer's life. He was born in Trier, Germany, in 1815 where he studied mathematics and the natural sciences. He worked for the famous mathematician and physicist, Julius Plücker (1801–1868), in Bonn, Germany. Beer eventually received a PhD in mathematics and published a book in 1854 titled *Einleitung in die höhere Optik*. His work, along with that of Lambert and Bouguer, the German and French eighteenth-century mathematicians, constitutes Beer's Law.

A version of the Beer–Lambert law is also used to describe the absorption of solar radiation as it travels through the atmosphere. Its application and relevance is dependent with respect to the degree the sun's light is perpendicular to the observer on Earth's surface.

See also Ramsay; Tyndall

BEHRING'S THEORY OF IMMUNOLOGY: Biology: *Emil Adolph von Behring* (1854–1917) Germany. Emil von Behring was awarded the first Nobel Prize for Physiology or Medicine in 1901 for his discovery of antitoxins that are produced by humans to counteract the toxins (poisons) produced by bacteria in the body.

> *The blood of animals will produce substances that can neutralize toxins, that is, poisons caused by invading organisms such as bacteria, and that antitoxins similar to antibodies will fight the disease-causing organisms.*

Emil Behring, the son of a small town schoolteacher with a large family, was a brilliant child who, with the assistance of the local preacher, was able to attend the Gymnasium (high school) in Hohenstein in Saxony. He then attended the Academy for Military Doctors at the Royal Medical-Surgical Institute in Berlin. After receiving his medical degree, he entered the Army Medical Corps where he served as a troop doctor and later became a lecturer in the Army Medical College in Berlin. Following his military service he was employed at the Hygiene Institute of Berlin and became an assistant to Robert Koch (1848–1910), the well-known German physician and bacteriologist. At this point in his career, Behring studied and experimented with the development of a therapeutic serum that led to successful treatments for **diphtheria** and **tetanus**. His first successful therapeutic serum treatment took place in 1891. It involved a child who was suffering from diphtheria. These first treatments were not successful because the antitoxins were not strong enough. After more research, an improved protocol, using a mixture of the toxins along with the antitoxins now derived from larger animals such as sheep, and later horses, proved successful. As with many such inoculations, there were adverse reactions to the treatment serum, but in the long run diphtheria and tetanus as devastating diseases have been conquered. Behring received many awards during his long career and went on to develop treatments for other diseases including a vaccine for the immunization of calves against tuberculosis. He spent the end of his career attempting, unsuccessfully, to develop a vaccine for human tuberculosis.

Behring, along with Shibasaburo Kitasato (1856–1931), a Japanese bacteriologist, proposed a serum theory that led to their development of an antitoxin for diphtheria and tetanus (a form of blood poisoning). They demonstrated that giving animals graduated doses of tetanus bacilli caused the animals to produce in their blood substances that could neutralize the toxins that these bacilli produced. These were called *antitoxins*. They also demonstrated that the antitoxins produced by one animal could immunize another animal and that it could also cure an animal showing signs of diphtheria. Their research was confirmed and replicated by others.

Using this information Behring collaborated with Ehrlich to develop similar antitoxin immunity for diphtheria, a major killer of children at that time in history. It might be of some interest that the best antitoxin was made from injecting horses and then using blood serum from the infected horse as the source of the antitoxin. It was also discovered that by mixing a small amount of the original toxin (poison) with the serum antitoxin, the treatment for tetanus and diphtheria was more effective.

See also Ehrlich; Jenner; Koch

BELL'S LAW (ALSO KNOWN AS THE BELL–MAGENDIE LAW): Medicine: *Sir Charles Bell* (1744–1842), Scotland.

> *The anterior spinal nerve roots contain only motor fibers, and posterior roots only sensory fibers.*

Bell's major work in 1811 was the first to refer to the motor functions of the ventral (abdominal) spinal nerve that established the sensory functions of the dorsal roots. This, along with the discovery made by the French physiologist, François Magendie (1783–1855), that damage to the dorsal root and anterior root in spinal nerves destroys both the sensory and motor activity, enabled Bell to arrive at Bell's law that is based on anatomical evidence. This discovery is considered one of the greatest in the history of physiology. He demonstrated that the spinal nerves were able to transmit sensory and motor functions. In addition, he found that the sensory nerves traverse the posterior roots whereas the motor nerves go through the anterior section. Evidence of Bell's law was confirmed by experiments conducted by Magendie, who is considered a founder of experimental physiology, and the German physiologist and anatomist Johannes Peter Müller (1801–1858) who used frogs to demonstrate the theory because it was easier to extract their spinal cords than it was for small mammals. Magendie believed living organisms were merely complex systems that could be subjected to all types of experimentation with impunity. He used living cats, dogs, and rabbits without seeming to care about their pain or discomfort.

Sir Charles Bell received his medical degree in 1799. In 1824 he became the first professor of anatomy and surgery of the College of Surgeons in London. In cooperation with his brother John Bell (1763–1820), also a surgeon, they wrote and illustrated a two-volume medical text titled, *A System of Dissection Explaining the Anatomy of the Human Body*. Bell wrote an earlier book in 1811 called *An Idea of a New Anatomy of the Brain* in which he describes his various experiments with animals and his ability to distinguish between sensory and motor nerves, which was a first. Many physiologists considered the work described in Bell's 1811 text to be the foundation of clinical neurology. In 1826 he was elected a Fellow of Royal Society and was knighted in 1831. Bell established a new hospital and medical school in 1828.

Bell may be best known to the general public for discovering the paralysis of facial muscles caused by a lesion of the facial nerve—known as Bell's palsy, as well as his discovery of a related problem, Bell's spasm, which is the involuntary twitching of the facial muscles.

BERGERON'S THEORY OF CLOUD PROCESSES: Meteorology: *Tor Harold Percival Bergeron* (1891–1977), Sweden.

> *Water vapor is formed as a result of water evaporating from supercooled drops that then are attached to ice crystals that either fall as snow or melt and fall as cool rain, depending upon local temperatures.*

Between 1925 and 1928 Bergeron worked at the Geophysical Institute in Stockholm and, after teaching at Oslo University, was elected as the head of the Meteorological Institute in Uppsala. As a meteorologist, Bergeron collaborated with his German colleague Walter Findeisen (1909–1945), thus, the theory is also known as the "Bergeron–Findeisen theory." The theory is based on their discovery of the mechanism for the formation of precipitation (rain, snow, and ice) in clouds. In 1935 Bergeron wrote a paper titled "On the Physics of Clouds and Precipitation" that documents the change in state from a vapor to a liquid water, which is called condensation. He arrived at the Bergeron process while walking in the mountains where the humidity was high and it began to rain.

We now know that there is more to the process than Bergeron's idea that the saturation vapor pressure with respect to ice is less than the saturation vapor pressure with respect to water. There are several other conditions that result in condensation besides the Bergeron process as follows: 1) when the relative humidity on the surface of Earth reaches 100% and 2) when vapor pressure is the same as the saturation vapor pressure. The primary difference is that, in clouds, the water will not condense until the saturation point reaches a level of supersaturation of about 120%. This level is required for the cloud droplets to overcome the natural surface tension of drops of water. Oddly, the pure water in the atmosphere requires some air pollution (called "aerosol") for the vapor to have something on which to condense and form droplets. Contrary to common beliefs, water vapor in clouds does not condense on itself when the temperature drops in rain clouds, but rather it condenses on tiny particles of matter (less than 2 microns) called nuclei that are forms of air pollution. These nuclei must be below freezing for this process to occur. Once the droplets are formed on the nuclei, air currents cause them to collide and coalesce with each other to form snowflakes—or raindrops carry them. These processes are referred to as ccn (cloud condensation nuclei).

Note: Pure water does not freeze at 0°C, and at temperatures below this point, liquid water is called supercooled water. This is important for another method of forming rain or snow. It is not until the temperature drops lower than freezing that the aerosol pollutants (called freezing nuclei) are cold enough to allow the supercooled cloud droplets to freeze onto these nuclei. This process does not occur until the temperature of the freezing nuclei reaches about −10°C.

BERNOULLI'S LAW OF LARGE NUMBERS: Mathematics: *Jakob (Jacques) Bernoulli* (1654–1705), Switzerland.

> *The average of a random sample from a large population is likely to be close to the mean of the entire population.*

This law of large numbers is a fundamental principle of statistical sequences that can be expressed in another way: The probability of a possible event (no matter how likely or unlikely) occurring at least once in a series of events increases with the number of events in the particular series. Jakob also is known for his work in permutations and combinations. The law of large numbers is sometimes referred to as the principle of probability, meaning that the probability of an event occurring at least once increases in likelihood if the number of events is large enough or approaches infinity. This can be interpreted in several ways. For example, when an increasing number of lottery tickets are sold, the odds increase that there will be at least one winner; whereas if only a few tickets are sold, the odds of a winner decrease drastically. Another way the law of large numbers may be interpreted is related to the differences in the concepts of "possible" and "probable." Anything might be considered possible. Even so, the term "possible" is not quantifiable, whereas the concept of "probable" is quantifiable in a statistical sense ranging from 0.1 to 1.0 or a scale of one (or it may be thought of a scale of 10 or 100%). The probability of an event occurring or not occurring in a nonstatistical sense may be thought of as "likely" or "unlikely" or "reasonably" or "unreasonably." There is no statistical scale for a "possible" event to occur or not occur even for an infinite number of events. This means that a "possible" event is not likely to occur or that it is most unlikely to have occurred in the past. This is the reason why the term "possible" should not be used in a courtroom because the term has no quantifiable or definitive meaning in determining guilt or innocence. After all, according to the law of large numbers, it is also possible for anyone to have committed the crime unless there is evidence establishing a high "probability" of a specific suspect.

Jakob Bernoulli and Johann Bernoulli (1667–1748) were brothers. (Daniel Bernoulli was the son of Johann Bernoulli.) Jakob's and Johann's father, Nicolaus Bernoulli (1623–1708), discouraged their ambitions as mathematicians and encouraged them to have careers in medicine instead. Jakob had degrees in mathematics and theology, Johann in iatromathematics and medicine. The brothers were rivals with each other throughout most of their lives. Part of this rivalry started as a disagreement over how to solve the problem of finding the shortest path between two points of something moving all by itself as influenced by the force of gravity. This problem led several mathematicians, including Leonhard Euler, in the direction of the field that became known as calculus. Their rivalry was not limited to their related work in the field of mathematics but continued in all aspects of their relationship and that of Johann's son, Daniel.

Jakob was involved in the development of and popularization of the new field of integral and differential calculus. Calculus, a field of mathematics dealing with differentiation and integration, was constructed by Sir Isaac Newton and Gottfried Leibniz. Jakob's contribution was in demonstrating how calculus could be used in practical ways in various fields of mathematics, whereas Johann's interest in this field was to support the version of calculus proposed by Gottfried Leibniz. Johann claimed that Leibniz's version had priority over Newton's calculus. Johann's interest extended beyond mathematics and included the fields of astronomy, chemistry, and physics. Even today the controversy of who invented calculus is not settled.

See also Bernoulli (Daniel); Euler; Leibniz; Newton

BERNOULLI'S PRINCIPLE: Physics and Mathematics: *Daniel Bernoulli* (1700–1782), Switzerland.

The sum of the mechanical energy of a flowing fluid (the combined energy of fluid pressure, gravitational potential energy, and kinetic energy of the moving fluid) remains constant.

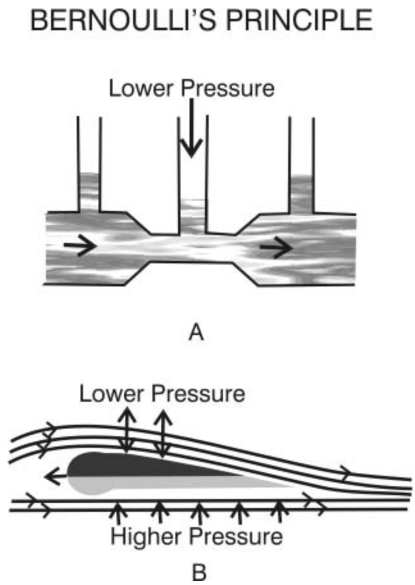


Figure B3. As the speed of the flow of a fluid (air or liquid) increases, the pressure decreases (and vice versa).

Daniel Bernoulli's principle is related to the concept of energy conservation of ideal fluids (gases and liquids) that are in a steady flow. This principle, used by mathematicians and engineers to explain and design many machines, further states that if fluid is moving horizontally with no change in gravitational potential energy and if there is then a decrease in the fluid's pressure, then there will be a corresponding increase in the fluid's velocity (or vice versa). One example of this aspect of the principle is the design of airplane wings. The air that flows over the upper curved surface of the wing moves faster than the air that passes past the underside of the wing, thus creating a pressure differential. In other words, the air must travel faster over the curved top of the wing and thus the pressure is less (i.e., the air molecules are spread further apart). While on the underside of the wing, the air flows slower (molecules closer together) and thus exerts greater pressure. This causes the wing to be "pushed" up, keeping the moving aircraft in flight. This upward pressure on the wing is called *lift*, but it might be more appropriate to call it *push*.

A similar part of the Bernoulli principle states, for example, that if there is a partial constriction in a pipe or air duct, the velocity of the fluid (gas or liquid) will increase as the pressure increases. This is known as the *Venturi effect* and can be demonstrated by the narrow nozzle of a garden hose that constricts, and thus speeds up, the flow of water as the water pressure forces the same amount of water through a smaller opening. A spray bottle or atomizer works on the same principle. It is named after the Italian physicist Giovanni Battista Venturi (1746–1822) who first described the effect by constrictions on water flowing in channels.

Bernoulli laid the groundwork for Robert Boyle's work in gases when he proposed a model for gases that consisted of many small atoms that were in constant motion and that exhibited elasticity as they bounced off each other as well as the sides of its container.

Daniel Bernoulli was interested in philosophy, logic, medicine, and mathematics. Bernoulli developed an equation that oddly received the name "Bessel functions." Named after the German mathematician, astronomer, and systematizer, Friedrich Bessel, Bessel functions are solutions involving cylindrical or spherical coordinates and are important for solving problems of wave propagation and signal processing. In 1724 Daniel Bernoulli published work in differential equations, which was well received throughout Europe. Following this publication he was appointed professor of mathematics at the University of St. Petersburg and later as professor of physics at the University at Basel in Switzerland where his father, Johann Bernoulli, formerly held the chair in mathematics. He also made contributions to probability theory, the kinetic theory of gases, electrostatics, and was a pioneer in the field of hydrodynamics.

See also Bernoulli (Jakob); Bessel; Boyle

BERZELIUS' CHEMICAL THEORIES: Chemistry: *Baron Jöns Jakob Berzelius* (1779–1848), Sweden.

Berzelius' electrochemical theory: *Molecules that make up compounds carry either a negative or positive electric charge.*

Baron Berzelius' work with the electrochemical nature of chemical reactions led to his concept of **catalysts** being related to the speeds at which chemical reactions take place. He not only gave this concept the name "catalyst" but also coined the names "protein" and "isometric." However, his positive-negative or, as it became known, his dualistic view of compounds did not hold up very well for future theories related to organic chemistry.

Berzelius' theory for chemical proportions: *The proportion of chemicals in a reaction is related to the masses (atomic weights) of the molecules involved in the reaction.*

His theory of chemical proportions allowed Berzelius to develop an accurate table of atomic weights for elements and molecules. Somewhat oddly, despite understanding the proportional relationship of atomic weights in chemical reactions, he did not accept Avogadro's hypothesis or number (*see* Avogadro). Even so, his accurate measurements of atomic weights of chemicals were one of his most important contributions to chemistry. His table of atomic weights was a precursor to the establishment of John Dalton's atomic theory.

Berzelius' theory of radicals: *Groups of atoms can act as a single unit during a chemical reaction and have at least one unpaired electron.*

Baron Berzelius named these groups of atoms "radicals" because of their nature to act as a singular electrically charged unit (ions), for example, OH, NH4+, $SO4^-$, and NO_2^-, all of which have a charge. They are short-lived, highly reactive charged particles that can initiate a chemical reaction by splitting molecular bonds. It was later discovered that ionizing radioactivity causes illness, including radiation poisoning, and death. Other causes for the formation of free radicals in the tissues of living organisms are not completely understood, but their formation is related to normal metabolism within organisms. The role of free radicals as they affect cells and accelerate the aging process in humans continues to be studied.

Berzelius had a difficult time in securing an education. He was forced to leave the University of Uppsala in Sweden to secure employment to finance his further education. He worked as a chemist testing the local water supply. Although he finally received his medical degree, he chose to work with Wilhelm Hisinger (1766–1852), the Swedish mineralogist, in the field of mining chemistry. Together they discovered the elements cerium, selenium, and thorium and assisted in the discovery of lithium and vanadium. (The German chemist Martin Klaproth (1743–1817) is also given credit for the discovery of cerium.) Berzelius was a meticulous researcher who kept accurate records and published over 250 papers. His textbook on chemistry published in 1808 was translated into several languages. Later, in 1818 he published an important paper titled "Essay on the Theory of Chemical Proportions and on the Chemical Effects of Electricity." Berzelius also developed the system for abbreviating the elements by the first one or two letters of their names (e.g., *H* for hydrogen, *O* for oxygen, *S* for sulfur, *Na* for Natrium [sodium], *Co* for cobalt, and *Ra* for radium).

Berzelius was not as successful in the field of organic chemistry as he was in inorganic chemistry. His insistence on the importance of his "dualistic theory" became an obstacle for future development in that field. Even so, his contributions to the field of organic chemistry were significant. His introduction of the concept of organic radicals (molecular fragments with an electrical charge) was a large step in the understanding of organic chemistry, particularly when it led to the discovery of the benzol radical. (Note: The term "benzol" is an archaic term for "benzene.")

As mentioned, his textbook on chemistry published in the early 1800s was well accepted in universities. It went through many printings and was translated into many languages except English. Berzelius was creative and invented a number of the chemical supplies, equipment, and terms used in today's laboratories. These included rubber tubing, protein, isomerism, catalyst, radical, and filter paper.

See also Avogadro; Dalton; Dumas

BESSEL'S ASTRONOMICAL THEORIES: Astronomy and Mathematics: *Friedrich Bessel* (1784–1846), Germany.

A star's distance from Earth can be determined by measuring its parallax.

Bessel cataloged the positions of over fifty thousand stars up to the ninth magnitude and was able to determine the parallax of 30 seconds for the star 61Cygni. From this calculation he was able to measure the star's distance from Earth as over 10+ light-years, which is now correctly determined to be 11.2 light-years distant. In 1838 Bessel proclaimed that he had determined the parallax for the star 61Cygni. It was difficult to measure the parallax for stars because they are so far from Earth and the instrumentation at the time was inadequate. Also, he was not the first to do so. That honor goes to Thomas Henderson who measured the parallax for the triple-star system Alpha Centauri in 1832. (A simple experiment to recognize parallax involves holding your index finger about 12 inches in front of your face, then closing one eye and then the other. Notice that the finger seems to jump to the left and then to the right. This phenomenon becomes less obvious and less measurable as distance increases.)

Bessel's theory of double star systems: *When the orbit of a bright star is displaced, the displacement is caused by a "dark companion" star that forms a two-star system.*

In 1844 after careful observations of wave-like motions of Sirius, the brightest star in the sky, he correctly determined that it was a double star system and its mate was a dark body that, though not visible, was the cause for the slight displacement of Sirius. Using the same rationale he employed for his theory of the movement of Sirius, he determined that the gravitational motion displacement for the planet Uranus indicated the presence of an unknown planet beyond Uranus. After his death and as he predicted, the planet Neptune was discovered in 1846 by the German astronomer Johann Gottfried Galle (1812–1910). However, Galle used calculations provided by Urbain LeVerrier (1811–1877), the French astronomer.

As a young man Bessel was trained as an accountant and was employed by an import-export firm. His interest in navigation eventually led to his pursuits in astronomy and mathematics. He refined the calculation for Halley's Comet, which started his success in the field of astronomy. After a friend secured him a position as an assistant at the Lilienthal Observatory in Saxony, he made accurate observations for the positions of over three thousand stars. At one time, the Lilienthal Observatory was the best-equipped observatory in the world. This success led to a commission to build an observatory at Königsberg (now Kaliningrad, Germany) where Frederick William III of Prussia appointed him as the observatory's director. He held this position until his death in 1846. Bessel had no university education but was highly respected by his

Bessel was one of many scientists interested in calculating the shape of Earth. Back in the sixth century BCE Pythagoras calculated that Earth was a sphere, and three hundred years later Eratosthenes calculated the size of Earth. In the late 1600s Jean Richter (1630–1696), a Frenchman, determined that his pendulum time machine was 2 minutes slower when he measured time at the Equator than it was in Paris. Isaac Newton claimed that Earth was flattened at the poles and thus was shaped as a "rotating spheroid." Others came to similar conclusions. Bessel used the imaginary meridian arcs in the sky that correspond to Earth's longitudinal lines in his 1832 calculations to determine that the shape of Earth was an elliptical spheroid.

In mathematical terms a spheroid is a quadric surface in three dimensions that can be formed by rotating an ellipse about one of its major axes; if the ellipse is rotated around its minor axis (rather than its major axis), the surface of the ellipse will take the shape of an *oblate spheroid*. This shape is similar to the "pancake" shape of Earth where the diameter from the North Pole to the South Pole is less then the distance of the diameter of Earth at the Equator. The rotation of Earth on its north/south axis creates the bulge of about 25 miles greater diameter at the Equator than is the diameter from pole to pole.

peers. The largest crater in the moon's Mare Serenitatis (Sea of Serenity) is named after him.

Not withstanding Bessel's contributions to astronomy, he may be better known for "Bessel functions," which is a mathematical theory to determine celestial motion that is influenced by gravity that causes perturbations. Oddly, Bessel functions, which were actually discovered by the mathematician Daniel Bernoulli, refer to a method for solving Bessel's differential equations. (Note: A detailed analysis of differential equations and the various form of Bessel functions of the first and second kind, as well as other applications, is beyond the discussion in this book.) The Bessel function is also useful in finding solutions to Laplace's equations and the Helmholtz equation in cylindrical and spherical coordinates related to wave propagation in the field of communications.

Bessel used his theory of functions to determine the motions of two or more bodies under the influence of mutual gravitation. His work in mathematics and astronomy enabled future astronomers and physicists to arrive at new astronomical observations. Bessel functions also assist in the study of the flow of heat and electricity through cylinders and spheres, as well as solving problems related to the wave functions in electricity and hydrodynamics.

See also Bernoulli (Daniel); Halley; Laplace

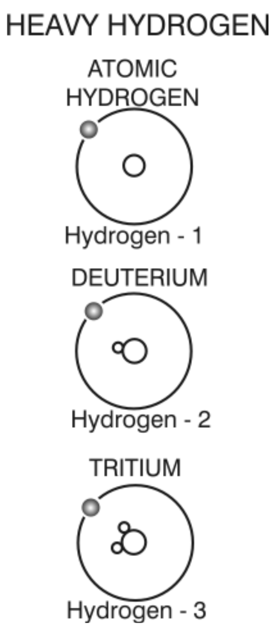


Figure B4. Structure of the three isotopes of hydrogen atoms.

BETHE'S THEORY OF THERMONUCLEAR ENERGY: Physics: *Hans Albrecht Bethe* (1906–2005), United States. Hans Bethe was awarded the 1967 Nobel Prize for Physics.

> *Carbon-12 atoms found in all stars undergo a series of catalytic reactions that convert hydrogen nuclei into helium nuclei through the process of a thermonuclear reaction, releasing 17.5 million electron volts of energy (17.5 MeV).*

Bethe's theory became known as the *carbon cycle*. Others had previously determined the sun is composed of about 85% hydrogen and 10% helium. Bethe postulated his thermonuclear theory as the explanation for the tremendous, long-lived source for the energy produced by the stars, including our sun. Although the thermonuclear reaction involving just one carbon-12 atom and a few hydrogen nuclei will not produce much energy, the stars have an enormous quantity of hydrogen. This reaction has continued over billions of years and produces prodigious amounts of energy. One unsolved problem was why the reaction did not take place faster and blow up the stars similar to a hydrogen (thermal fusion) bomb. Herman Ludwig Ferdinand von Helmholtz suggested that gravitational forces slowed the contraction of hydrogen to keep the system running. This theory did not hold up. Sir Arthur Stanley Eddington suggested that the hydrogen-to-helium reaction could be sustained in the stars if their centers contained very high-temperature gases that would force the nuclei together. Experiments on Earth with high-pressure and temperature-heavy hydrogen plasmas (highly ionized gas) to replicate the fusion process of the sun indicated that Bethe's and Eddington's theory is correct.

The essence of this thermonuclear reaction is that four protons (4 H^+) are converted into helium nuclei ($2He^{++}$), with the carbon-12 atom acting as a catalyst that is not consumed. The hydrogen protons involved are isotopes—deuterium (D) and tritium (T)—which are forms of heavy hydrogen. The reaction can be written as: $D + T + e \rightarrow {}^4He + n + 17.5$ MeV of energy, where *e* is an input of energy required to start the reaction and *n* is radiation. This process led others to develop the "fusion" H-bomb, which is many times more destructive than the nuclear "fission" atomic bomb but produces less harmful radiation. For the past half-century, research had attempted to achieve a similar controlled thermonuclear reaction to produce prodigious amounts of controlled energy for the production of electricity.

See also Gamow; Hoyle; Teller

BIOT–SAVART LAW: Physics: *Jean-Baptiste Biot* (1774–1862) and *Felix Savart* (1791–1841), France.

> *The intensity of the magnetic field set up by a current flowing through a wire varies inversely with the distance of the field from the wire.*

The Biot–Savart law means that the intensity of a magnetic field that is set up by an electric current flowing through a conductor (wire) will vary inversely with the distance of the magnetic field from the wire.

Jean Biot and Felix Savart were French physicists at the Collège de France in Paris where they studied the relationship between the flow of electrical current and magnetism and arrived at the law that is named after them. This law follows other laws of electricity such as Coulomb's law, Ampère's law, and Gauss' law. As a practical statement, it is an analogy between magneto-statics and fluid dynamics that is used to calculate magnetic responses and current density (amperes) in fluids. More recently the Biot–Savart law was used in the calculation of the velocity of air induced by vortex lines in aerodynamic systems because a vortex in fluids (air) is analogous to the velocity of a current's (amps) strength through a magnetic field.

In addition to electromagnetism, Biot was interested in other areas of physics. He was the first person to determine the optical properties related to the polarization of light as the light passes through a solution. He also was the first to determine the optical properties of mica, which is found in the mineral *biot* that was named after him. For his work on polarization he was awarded the Rumford Medal of the Royal Society. He later wrote a book in which he proposed that the shape of Earth might be based on its rotation on its axis. In 1804, along with Joseph Gay-Lussac, he flew a hot-air balloon to an altitude of 5 kilometers as they explored the changes in Earth's atmosphere. A small crater on the moon is named for Biot.

Felix Savart (1791–1841) actually discovered the law related to how the flow of current through a magnetic field is related inversely to the distance of the field from the magnet in 1820 during his collaboration with Jean Biot. Jean Biot was Savart's mentor and was senior in age and academic position at the Collège de France. Savart was also interested in acoustics. He invented the Savart disk that, using a cogwheel as a measuring tool, produced a sound wave of a known frequency. In addition, the *savart* which is a unit of measurement for musical intervals is named after him although it was actually invented by the French mathematician and physicist Joseph Sauveur (1653–1716).

See also Ampère; Coulomb; Gay-Lussac

BIRKELAND'S THEORY OF THE AURORA BOREALIS: Physics: *Kristian Olaf Bernhard Birkeland* (1867–1917), Norway.

The aurora borealis is caused by rays (charged particles) from the sun that are trapped in Earth's magnetic field and concentrated at the polar regions.

The aurora is a curtain-like, luminous, greenish-white light produced by upper atmospheric atoms and molecules that become ionized after being struck by electrons, thus emitting radiation. It is a large-scale electrical discharge affected by the solar wind and Earth acting as a **magnetosphere** "generator" that concentrates the aurora at the polar regions.

Kristian Birkeland studied this phenomenon for some time and arrived at his theory from his knowledge of cathode rays recently produced and named by the German physicist Eugen Goldstein (1850–1930). He recognized the relationship of the glowing charged particles in cathode rays whose directions could be altered by magnetism.

Birkeland made another important contribution involving the great worldwide demand for nitrogen fertilizer. The major supply of fertilizer was limited to guano (bat dung found in caves) and some natural nitrogen compounds. However, the atmosphere is about 78% nitrogen and could be an almost unlimited source of nitrogen fertilizer. In 1903 Birkeland and the Norweigian engineer and industrialist Samuel Eyde (1866–1940) developed a process by which air was passed through an electric carbon arc and produced nitrogen oxides, which were then dissolved in water to form nitric acid. The nitric acid reacted with lime to form calcium to produce calcium nitrate, an excellent fertilizer. It required great amounts of electricity to operate the electric arc. As a consequence, the commercialization of the process led to the development and the growth of hydroelectric power in Norway. This process became known as the Birkeland–Eyde process that produced fertilizer for export worldwide before World War I. About the same time another process that involved a catalytic reaction with hydrogen was developed that used the "free" nitrogen from the atmosphere and converted it into "fixed" nitrogen. The resulting nitrogen oxides, the basis for fertilizer, were less expensive to manufacture than those produced by the Birkeland–Eyde process. This alternate process became known as the Haber process using an electric arc as a means of fixing atmospheric nitrogen. The process was commercialized by the German chemist and engineer Carl Bosch (1874–1940) and is still used today to produce the worldwide demand for fertilizer.

See also Haber

BJERKNES' THEORY OF AIR MASSES: Physics and Meterology: *Vilhelm Friman Koren Bjerknes* (1862–1951), Norway.

> *The thermodynamic properties of an air mass will determine the weather factors for the area that is covered by the air mass.*

Essentially, this means that the physical nature of an air mass is partly determined by the nature of the surface region over which it develops.

Bjerknes was the head of the geophysics department at the University of Leipzig in Germany before establishing the famous Bergen Geophysical Institute in Bergen, Norway, in 1917, which laid the foundation for the Bergen School of Meteorology. In collaboration with his son Jacob Bjerknes (1897–1975), a renowned meteorologist in his own right, they established a series of weather stations in Norway. As a result of the data and research gathered from these stations, Vilhelm Bjerknes developed his theory of air masses and cold (polar) fronts. He recognized that there were at least four types of air masses: equatorial, tropical, polar, and arctic (and antarctic). An air mass is a very large dome of air, which internally has similar factors of temperature, humidity, and pressure. Some fifty air masses exist over the surface of Earth at any one time, and their nature reflects the region from which they were spawned. Bjerknes used these and other factors to develop a system that distinguished properties that determine the weather, such as humidity, temperature, and visibility (based on the amount of dust in the atmosphere). He recognized that the mass movement of air could better be predicted when the hydrodynamics, such as polar fronts, squall lines, and low-pressure areas (cyclonic regions) of large massive weather system were understood. The movement of air masses, related hydrodynamics, and the refinement of his classification system for air masses in the atmosphere are the bases for today's weather predications and reports.

As a young boy Vilhelm assisted his father, Carl Bjerknes, in setting up and conducting experiments in hydrodynamics. He continued this work until he entered the University of Kristiania. (The city of Kristiania was renamed Oslo in 1925.) He wrote his first scientific paper "New Hydrodynamic Investigations" in 1882 when he was just twenty years old.

Prehistoric humans, no doubt, were aware of weather and changes in atmospheric conditions that affected their lives. They could tell if a weather front was upon them by the mere fact that they became colder or hotter, or that it was humid or wet, as well as windy. During the ice ages they were well aware of the seasons and prepared for long winters. People always could, and still do, recognize repeated patterns of the weather and sense the difference between hot/cold, wet/dry, cloudy/bright, and calm/windy. There are records that indicate the ancient Greeks understood that weather changed when masses of air passed through their region. In about 400 BCE, Hippocrates wrote a piece "On Air, Water, and Places" that describes changes in weather and how directions of the wind entering the city could affect the health of citizens.

Until about the seventeen century observing the weather was accomplished by folk tales, myths, and legends. Some of the tales still exist. For instance, the amount of hair on a certain type of caterpillar will predict how cold the winter will be, and the predictions of the famous Punxsutawney Phil groundhog that comes out of his hole on the second day of February each year are but two examples. If the sun is shining and "Phil" sees his shadow, there will be six more weeks of winter; and if he does not see his shadow, spring will come early.

Despite all the knowledge, equipment, computers, satellites, and theories at hand today, weather forecasting is still somewhat unreliable due to the enormous amount of constantly shifting variables involved that are beyond the capabilities of our best efforts to incorporate them into a forecast that is accurate for more than a few days.

He then moved to Germany to continue his studies, returning to Norway in 1907 where he remained for the next five years before going to the University of Leipzig as the head of the geophysics department. He presented his theory in a 1921 paper titled "On the Dynamics of the Circular Vortex with Application to Atmosphere and to Atmospheric Vortex and Wave Motion." His theory is based on the direct analogy of the flow of fluids (air and water), turbulence, and whirlpools in water to the behavior of air masses. In other words, he applied his father's work on hydrodynamics and electrodynamics to air masses.

BLACK'S THEORIES OF HEAT: Chemistry: *Joseph Black* (1728–1799), Scotland.

There are three aspects to Black's theory. One deals with solids changing to liquids (fusion), one involves the change of liquids into gases (vaporization), and the third relates the capacity of heat required to a specific temperature change of a given mass.

Black's theory of latent heat of fusion: *The heat of fusion is the heat capacity required to change 1 kilogram of a substance from a solid to a liquid without a temperature change.*

Black's theory of latent heat of vaporization: *The heat of vaporization is the heat capacity required to change 1 kilogram of a substance from a liquid to a gas without any temperature change.*

Black's theory of specific heat: *Specific heat is the amount of heat required to raise 1 kilogram of a substance by 1 degree Kelvin.*

Joseph Black proposed these theories after experimenting and making many measurements involving changes in the states of matter (e.g., water to ice and boiling water to steam; see Figure B5). He was the first to distinguish between temperature and heat, a distinction that many still confuse today. *Temperature* is based on the law of thermodynamics and is the degree of hotness or coldness transferred from one body to another as measured in degrees Celsius, Kelvin, or Fahrenheit. Temperature is a measure of the average (mean) energy of the motion of molecules and atoms in a substance in internal equilibrium. *Heat*, on the other hand, is a form in which energy is transferred from one body to another. Heat always flows from a substance that contains more **energy** to one with less. Thus, the temperature of the first substance is reduced, and the second substance increases until equilibrium between the two substances is established. In other words, at equilibrium they are at the same temperature.

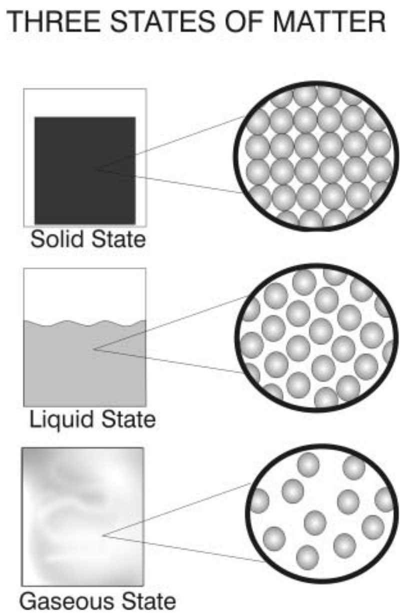


Figure B5. States of matter: A solid state exists when the substance has a definite shape and volume and tends to maintain its shape and volume. A substance in the liquid state has a definite volume but no definite shape; it flows and takes on the shape of it container. The liquid state is between the solid and gaseous states. A substance in the gaseous state has a lower density than solids and liquids, and it will expand to fill the extent of its container. The states of matter are related to the densities of matter and the kinetic energy of their constituent particles.

During the late eighteenth and early nineteenth centuries, a number of physicists developed the science of heat, later named *thermodynamics*, the second law of which states that heat flows naturally from hot to cold, but never the other direction. The second law of thermodynamics describes *entropy*, which is an increase in disorganization (of molecules) within a closed system until equilibrium is established.

In several ways, Black's work was the beginning of modern chemistry. More important, he was one of the first to measure chemical reactions quantitatively. For example, the reaction of limestone with acid that exhibited an effervescence that he called "fixed air," and that later proved to be carbon dioxide, was one of his more famous experiments.

See also Carnot; Clausius; Joule; Kelvin; Maxwell; Mayer; Thomson; von Helmholtz

BODE'S LAW FOR PLANETARY ORBITS: Astronomy: *Johann Elert Bode* (1747–1826), Germany.

Bode's law is a numerical system for determining the average radii (distance) of a planet from the sun, calculated in astronomical units (AU). An **AU** is the average distance of Earth from the center of the sun—approximately 93 million miles.

Start with a series of numbers where each number is twice the preceding number, namely, 3, 6, 12, 24, 48, 96–.–.–.–, then add 4 to each number, namely, 7, 10, 16, 28, 52, 100–.–.–.–, then divide the sum of each by 10. The answer is the mean radii of the planetary orbits in astronomical units (AU), which is the planet's mean distance from the sun—for example:

$$3 + 4 = 7 \div 10 = 0.7 \text{ AU}$$
$$6 + 4 = 10 \div 10 = 1.0 \text{ AU}$$
$$2 + 4 = 16 \div 10 = 1.6 \text{ AU}$$
$$24 + 4 = 28 \div 10 = 2.8 \text{ AU}$$
$$48 + 4 = 52 \div 10 = 5.2 \text{ AU}$$

Bode's law is really the mathematical expression of a concept proposed by the German astronomer Johann Titius (1729–1796) in 1766 or 1772. It is based on Titius's idea that a simple numerical rule governs the distance of planets from the sun. A few years later Bode proposed a useful combination of simple numbers that he claimed could predict the location of unknown planets. It is unknown if this is some true relationship of the nature of the solar system or just coincidence. Most astronomers of his day were unimpressed with his number sequence because the rule did not apply for the planets Neptune and Pluto. Bode's law predicted a planet between Mars and Jupiter, but none was found until the Italian monk, mathematician and astronomer Giuseppe Piazzi (1746–1826) discovered a very small (about 650 miles in diameter) asteroid-like planet, Ceres, in 1801. Ceres was located at 2.55 AUs from the sun in an area with many, many asteroids (also known as planetoids). Bode's law was finally accepted when Bode accurately predicted the location of a yet-to-be-discovered planet. Using a telescope, William Herschel located Uranus in 1781, exactly where Bode's numbers indicated it should be, at 19.2 AUs. Bode was given the privilege of naming this new planet, calling it Uranus after the Greek god of the sky.

BOHM'S INTERPRETATION OF THE UNCERTAINTY THEORY FOR ELECTRONS: Physics: *David Joseph Bohm* (1917–1992), United States.

> *The electron has a definite momentum and position and is thus a real particle, with wave and particle characteristics, but this duality is the result of new "pilot waves" that connect the electron with its environment.*

David Bohm did not completely agree with the Heisenberg uncertainty principle (indeterminacy principle) or with then current interpretations of **quantum** theory. He considered Heisenberg's theory as presenting only a *description* of the behavior of an electron and not a *view* of the electron because it stated neither the position nor momentum (mass multiplied by velocity) of the electron could be determined at the same instant. Bohm claimed that this uncertainty does not represent the **deterministic** nature of reality—that is, an event cannot precede its cause.

Bohm's pilot wave is not the classical or traditional explanation of quantum or indeterminacy theories. It can be measured only by complex mathematics, not by experimentation. Although Bohm's pilot wave interpretation maintains the concept of "real nature" as being deterministic, it is not as well accepted, as is Bohr's interpretation. Today, most physicists accept the latter's theory.

See also Bohr; Dehmelt; Einstein; Heisenberg; Planck

BOHR'S QUANTUM THEORY OF ATOMIC STRUCTURE: Physics: *Niels Hendrik David Bohr* (1885–1962), Denmark. Bohr was awarded the 1922 Nobel Prize for Physics.

Bohr's quantum mechanics theory for atoms: 1) *Electrons reside in discrete energy levels (similar to the shells or orbits of Rutherford's model) in which they move. As long as they remain in their orbit, they do not emit radiation. Therefore, these energy levels (orbits) are stable and are always whole number multiples of Planck's constant as 1h, 2h, 3h, and so on, and the orbiting electrons are limited to a discrete series of orbits.* 2) *Electrons move in stable orbits because they can only emit or absorb discrete radiation ''packets'' of energy that are equal to the difference between the original and the final energy levels of the electrons. The quanta ''packets'' of energy are absorbed or radiated when electrons change from one orbit to another.*

Niels Bohr based his theory for the structure of the atom on Ernest Rutherford's famous experiment demonstrating that atoms comprised very small, heavy, dense, positively charged central nuclei surrounded at some distance by very light, negatively charged particles, referred to as *electrons*. This concept of the negative electrons orbiting the positive nucleus was somewhat similar to planets orbiting around the sun. This classical mechanical-electrodynamic concept presented a problem in the sense that electrons carry a negative electrical charge, and according to the laws of physics, they should radiate energy as they orbit the nucleus, which would result in instability and cause them to spiral into the positively charged nucleus. Thus the conservation of momentum would be violated. Bohr solved this problem of the atom's potential instability by postulating that the circumference of the orbit must be equal to an integral number of wavelengths. The extension of this idea led to the development of quantum mechanics.

To account for the conservation of momentum (mass times speed), Bohr assigned specific values to orbits and later to suborbits. This led to his concept that when an electron emitted a quantum of energy (photon), it would move to a lower orbit (lower energy level). Conversely, when an electron absorbed a quantum of energy, it would move to an outer or higher orbit (energy level). This became known as a *quantum leap*. By using Planck's constant ($\hbar$) he measured the difference in radiation for these energy level changes by $\hbar v$, where v is the frequency of the radiation. These developments led Bohr to another principle.

Bohr's correspondence principle: *The quantum theory description of the Bohr atom relates to events on a very small scale but corresponds to the older classical physics, which describes events on a much larger scale.*

This principle is based on electrons' obeying the principle of quantum mechanics but with limits corresponding to and similar to Newtonian classical mechanics. Thus, his model of the atom could exist only if electrons exhibited both wave and particle properties. This explains how electrons, as standing waves, could move in orbits without emitting radiation but still have particle characteristics. Bohr's next principle is related to the quantum nature of photons and electrons.

Bohr's complementary principle: *The electron can behave in two mutually exclusive ways. It can be either a particle or a wave.*

The wave–particle duality was demonstrated by others and is accepted today as the duality nature of quantum particles. Bohr also was the first to theorize that an electron could enter a nucleus and cause it to be excited and unstable. This led to his next contribution.

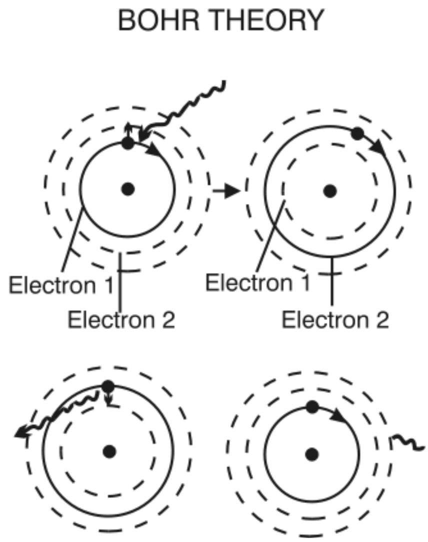


Figure B6. When electrons move from a stable energy level of atoms, they emit discrete packets of energy.

Bohr's theory of a compounded nucleus: *The nuclei of atoms are compounded or composed of distinct parts. The heavier the nuclei the more "parts" they contain and more likely to be unstable and break up.*

This led to his next theory.

Bohr's "droplet model" theory: *The impact of a neutron (corresponding to a "droplet") on a very heavy nucleus can cause the heavy nucleus to be compounded and become unstable and fission or split into two parts, whose total mass almost equals the mass and charge of the original heavy nucleus.*

Later, Otto Hahn who discovered *protactinium* (Pa), and German chemist Fritz Strassman (1902–1980) chemically identified fragmentary decay particles of uranium predicted in Bohr's model but did not identify it as **fission**. This decay reaction, called *nuclear* fission by Lise Meitner and Otto Frisch, occurs when "compounded" heavy nuclei break into two or more lighter nuclei. These experiments were the first evidence for fission of the rare uranium radioactive isotope U-235, which ended as a small radioactive isotope of barium-56. This led to the use of another fissionable element, plutonium, used in atomic fission bombs, which Bohr assisted in developing. Among Bohr's other contributions was his early (1920) theoretical description of the Periodic Table of Chemical Elements that he based on his theories of atomic structure.

See also Bohm; Dehmelt; Frisch; Hahn; Heisenberg; Meitner; Planck; Rutherford

BOK'S GLOBULES THEORY OF STAR FORMATION: Astronomy: *Bart Jan Bok* (1906–1983), United States.

> *The small, circular "clouds" of matter that are visible against a background of luminous gas or by the light from stars are actually massive "globular-like clouds" of dust and gas that are in the process of condensing to form new stars.*

Bart Bok identified these interstellar dark globules near the **nebula** Centaurus, referred to as IC2944. Bok's theory is used to explain one of the concepts for the origin of our universe. Recently his theory has been reexamined as a possible model for the creation, regeneration, or rebirthing of stars to explain the idea for the ever-continuing **universe**.

After receiving his PhD in the Netherlands, Bart Jan Bok arrived in the United States in 1929. He became a citizen in 1938 and was appointed professor of astronomy at Harvard University in 1947. From 1957 to 1966 he was director of the Observatory in Canberra, Australia. After returning to the United States in 1966 he became director of the Steward Observatory in Arizona and professor of astronomy.

In cooperation with his wife, Priscilla, they published a paper "The Milky Way" in 1941 that explained his theory for the spiral structure of the Milky Way. Walter Baade who identified hot young O and B type stars in the Andromeda galaxy further explored Bok's theory. These bright O and B stars act as identifiers in the arms of the spirals of the galaxy. In the early 1950s William Morgan and Hendrik van de Hulst produced data from radio-astronomy experiments that contradicted the circular spiral nature of galaxies. Their data identified them as being more elliptical in shape. Bok attempted to join the two different types of structures (circular vs. elliptical) for galaxies but was not successful. He is now best known for what are called *Bok globules* that are the small dark circular clouds that are visible against the background of stars.

See also Baade

BOLTZMANN'S LAWS, HYPOTHESES, AND CONSTANT: Physics: *Ludwig Edward Boltzmann* (1844–1906), Austria.

Boltzmann's law of equipartition: *The total amount of energy of molecules (or atoms) is equally distributed over their kinetic motions.*

In other words, on the average, the energy of molecular motion is distributed with discrete degrees of freedom within an ideal gas. This led to Boltzmann's description of how *the total energy of a gas is distributed equally among the molecules in the gas, namely, heat.* This became known as the Maxwell–Boltzmann distribution equation, which is based on the Boltzmann constant: $k = R/N = 1.38 \times 10^{-23}$ J/k, where *k* is the Boltzmann constant, *R* is the universal gas constant, *N* is the number of molecules in 1 mole of gas as per Avogadro's number, and *J/K* is joules per degree of Kelvin.

Boltzmann distribution equation: *The probability exists that a molecule of a gas will be in energy equilibrium with the position and movement of the molecule and will be within an unlimited range of values.*

This is another way of stating the energy distribution of gas molecules. It states that atoms and molecules should obey the laws of thermodynamics.

Boltzmann's entropy hypothesis: *The entropy (the measure of disorder in a closed system) in a given state is directly proportional to the logarithm of the number of distinct states available to the system.*

Entropy was the term given to the concept of the second law of thermodynamics. It is based on the fact that unless energy is added to a closed system, the system will always proceed to a state of disorganization and finally to a state of energy or heat equilibrium. Boltzmann supplemented the mathematics related to thermodynamics using a statistical treatment to interpret the second law of thermodynamics, which in essence states that heat can only move toward cold, or to a region of less heat, never the other way around. This hypothesis can be stated as the Boltzmann constant equation: $S/k = \log p + b$, where S is entropy and k is the Boltzmann constant, which has the value of 1.380×10^{-23} joules per degrees Kelvin. Boltzmann thought so highly of this equation that he had it inscribed on his tombstone. Most of Boltzmann's theoretical work contributed to the science of statistical mechanics. He is also known as the father of statistical mechanics.

See also Carnot; Clausius; Kelvin; Maxwell; Rumford

BONNET'S THEORIES OF PARTHENOGENESIS AND CATASTROPHISM: Biology: *Charles Bonnet* (1720–1793), Switzerland.

> *All organisms are preformed in miniature (homunculi) as little beings inside the female eggs of the species, and the ''germ'' of a species is constant over time, thus no male of the species is required for propagation of the species.*

Charles Bonnet developed this theory of parthenogenesis after discovering the female of a species of a tree aphid reproduced without the aid of male sperm (thus, parthenogenesis, or "virgin birth"). To overcome the objections to his theory, which implied all living organisms were unchanged from the beginning of time, he proposed the concept of catastrophism. Although he was the first to explain evolution in a biological context, and the first to use the term "evolution" in a biological sense, he did not accept the extinction and changes of species as a gradual process.

Bonnet was one of the first to propose catastrophism as the cause of changes (evolution) in biological species. According to his theory, catastrophic events on Earth result in great extinction of most species and that that new species are created from the few individuals that survived catastrophic events. He believed that catastrophism was responsible for apes becoming humans and that the next step is for humans to evolve into angels. Catastrophism as a concept, with modifications, is still accepted by a few biologists today.

The concept of "preformation" of humans in either the female egg or male sperm as a homunculus (small human form) persisted since the days of ancient Greek philosophers. Catastrophism influenced many biologists until Darwin's concept of a more gradual type of biological evolution, but even Darwin was aware that evolution was not "smooth" over periods of time and that there were "interruptions" in the process.

See also Aristotle; Buffon; Cuvier; Eldredge–Gould; Gould; Swammerdam

BOOLE'S THEORY OF SYMBOLIC LOGIC: Mathematics (Logic): *George Boole* (1815–1864), Ireland.

> *A mathematically (algebraic) logical construction is based on one of the following operators: AND, OR, or NOT, or is based on a construction that may be expressed by all three of these operators.*

Symbolic logic, and in particular Boolean logic, is indispensable for use in developing computer programs and computer-based research engines. This system is based on what mathematicians refer to as "elements" of the system and "sets." A set is a collection of things (such as a group of numbers) that have the characteristic that can be identified as being included in a collection of other things (other groups of numbers).

When using the English terms of OR, AND, and NOT, Boolean logic is the basis for computer programming languages as well as computer search engines, such as Google and Ask, although not all computer search engines use the same syntax. As an example of a common engine syntax:

Search for Students with last name = Jones AND first name = James;
Search for Students with last name = Jones OR first name = James;
Search for Students where NOT is last name = Jones

The Google search engine uses the AND syntax as a default in their program as a way to link two related or different items, e.g., "search Jones" "search James." In other words the AND is understood in their program and automatically gives you students with both names Jones and James. If you want to refine the search OR is used as in "search Jones OR James", and they use the – sign for the logical use of NOT, as in – "search Jones." Actually the Google program is more elegant than this simple Boolean logic suggests, but these techniques seem to speed up a more comprehensive search.

George Boole is sometimes thought of as mathematics genius because of his work in abstract algebraic operations that are expressed in his work on Boolean algebra and Boolean logic that are the bases for the programming language of computers. After his shopkeeper father taught him what math he knew, George continued to learn on his own all he could in mathematics as well as other fields, including Latin and Greek. When he was sixteen years old, he added to the family income by teaching school, and four years later in 1835 he opened his own school. He studied the works of other seventeenth-century mathematicians and just four years later published his first paper in *The Cambridge Mathematical Journal* in 1839 that discussed differential equations and invariance. On the basis of this paper and other works he became a professor of mathematics at Queen's College in Cork, Ireland. In 1844 he received The Royal Society Award for his work on differential equations. In 1847 he published *Mathematical Analysis of Logic*, and in 1854 he worked on the idea of applying mathematical approaches to symbolic logic, which he published in *An Investigation into the Laws of Thought*. This last publication before his death from pneumonia in 1864 established the field of symbolic logic later refined by the German mathematician, logician, and philosopher Gottlob Frege (1848–1925), the famous Welsh philosopher Bertrand Russell (1872–1970), and Alfred North Whitehead.

BORN–HABER THEORY OF CYCLE REACTIONS: Physics: *Max Born* (1882–1970), Germany. Born shared the 1954 Nobel Prize for Physics with Walter Bothe.

The sequence of energy involved in the chemical and physical reactions that form lattice ionic crystals is related to the crystal's initial state (zero pressure at zero kelvin), and to the crystal's final state, which is also at zero pressure and zero K (e.g., for a gas of infinite dilution).

The Born–Haber cycle is better known by the early work of Max Born, which resulted in the mathematical theory referred to as the cycle explaining how chemical bonds are the result of sharing or transferring electrons between atoms. As a result, several scientists applied quantum mechanics to the concept of chemical **bonding**. Born and others used the hydrogen atom as a model, and it was soon obvious that quantum mechanics could explain almost all aspects of chemistry, including the different types of reactions between atoms of different elements and the probability of where to find an electron within its orbit surrounding the nucleus.

Max Born is better known for his work in the field of quantum mechanics. In cooperation with German physicist Ernst Pascual Jordan (1902–1980), Born refined Werner Heisenberg's concept of *matrix mechanics* by developing the mathematics that explained the theory in 1925. Born was among the first to provide the mathematics to explain the possibility that particles can also behave like waves. This was about the time that the duality concept of light (photons) and other types of radiation was being discussed and debated.

See also Bohm; Bohr; Dehmelt; Frisch; Haber; Hahn; Heisenberg; Meitner; Schrödinger

> Fritz Haber (1868–1934) was born in Breslau, Germany, now Wrolcaw, Poland, and studied at the University of Heidelberg under Robert Bunsen. He and Carl Bosch developed the Haber process for the catalytic formation of ammonia from hydrogen using the nitrogen found in the free atmosphere. The Haber–Bosch process (not to be confused with the Born–Haber cycle) was a great development in the field of industrial chemistry because it greatly increased the supply of nitrogen for use in producing cheap nitrogenous fertilizer and WWI explosives for which he received the 1918 Nobel Prize in Chemistry. He also developed deadly war gases and was personally involved in their release. He also developed an effective gas mask during the war years. Haber converted from Judaism to be more acceptable to the German government. Even so, the Nazis forced him to emigrate because he was still Jewish by the Nazis' definition.

BOYLE'S LAW: Chemistry: *Robert Boyle* (1627–1691), Ireland and England.

> *There is an inverse relationship between the pressure and volume of a gas when the temperature remains constant. The equation for this law is written* as $P \times V = c$ (pressure times volume equals a constant inverse relationship).

Robert Boyle, an Irish chemist who later worked in England, used air pumps developed by Robert Hooke to experiment with the physical conditions of gases under differing pressures while maintaining constant temperatures. In 1661 he published the results in his book, *The Sceptical Chymist*. In 1662 Boyle discovered air could be compressed, and as the pressure increased, the volume decreased. He demonstrated that if the pressure on a gas doubled, its volume would be just one-half its original volume; if the pressure was increased by one-third, the volume would decrease one-third. Boyle also noted the opposite inverse relationship existed when he used a vacuum pump to decrease the pressure that increased the volume of air. This proved to be a classical inverse relationship, which seems to be a universal constant. It was an important conclusion because it helped explain the atomic (particle) nature of gases—that is, atoms (or molecules) of gases would spread farther apart when the pressure was decreased. Conversely, the atoms would be forced closer together if the pressure increased.

Boyle was an atomist who supported the original concept of matter first proposed by the ancient Greek Democritus. It took more than a century after Boyle's work before the modern atomic theory of matter was fully developed. It might seem ironic that a scientist who is considered one of the founders of modern chemistry was also an **alchemist** who spent much of his time attempting to transmute base metals into gold.

Robert Boyle was born into a wealthy aristocratic family who lived in a castle in Ireland. Like the sons of many aristocratic families, as a young boy he was sent off to schools in Switzerland and later to Italy. It is said that he developed an interest in science while at school when he found copies of Galileo's writings describing his work and ideas on astronomy. After his schooling, Boyle's family moved to their estate in England where in 1644 Robert retired for ten years, during which time he became interested in studying the nature of gases, then called pneumatics. He then moved to Oxford where he met Robert Hooke who had constructed an air pump that he used to demonstrate how air is important for respiration, combustion, and the transmission of sound. An important phase of Boyle's life was when he joined with Francis Bacon who supported the idea that science should be based on empirical observations and controlled experiments. This group originally known as the "Invisible College" became the famous Royal Society for the Improvement of Natural Knowledge in London in 1662.

In his famous book *The Sceptical Chymist* Boyle attacked the age-old concepts of Aristotle's four elements (earth, air, fire, and water) by proposing another ancient concept that matter is composed of basic particles and that different types of matter are identified by their number and position as well as the motion of these particles. He also stressed the importance of accurate empirical observations, planning and conducting well-designed experiments, and keeping records of the results. In addition, an important concept was Boyle's theory that heat was the result of the motion of the particles of matter. Later this idea was expanded into the kinetic theory of matter and the second law of thermodynamics. Boyle's law is a rather simple inverse relationship between the pressure and volume of a gas, assuming no change in the temperature of the gas. Boyle considered this law as the compressibility of air. In 1660 it was published in *New Experiments Physico-Mechanicall, Touching the Spring of the Air and its Effects*. The law is known as Boyle's law in the United States and Great Britain and as Mariotte's law in most of Europe. Edme Mariotte (1620–1684) was a French physicist and priest who recognized the validity of Boyle's law ostensibly before he published his findings in 1676. It is expressed as $p \times V = C$ (when C is the universal inverse constant, p is the pressure, and V is the volume of the gas).

See also Avogadro; Charles; Gay-Lussac; Ideal Gas Law

BRADLEY'S THEORY OF A MOVING EARTH: Astronomy: *James Bradley* (1693–1762), England.

Parallax exhibited by the stars indicates a movement of the earth.

James Bradley was the successor of Edmond Halley as the Astronomer Royal, during which time he erected a telescope in a stationary vertical position to observe the same spot in the sky each night. Over time he observed a slight displacement (**parallax**) of the image of the star Gamma Draconis. At first he thought this parallax of a star viewed over a period of time from the same place on Earth meant that only the star moved in relation to Earth. Bradley later realized it was not really the star's motion causing the parallax because the pattern of the star's displacement was repeated every six months. Thus, it meant the observer and his fixed telescope on a moving Earth caused the change in the star's apparent position. This concept is based on Earth's orbiting around the sun every twelve months, which means Earth is in a very different viewing position in relation to the star every six months. This creates an apparent displacement called *parallax*. The diameter of Earth's orbit around the sun is approximately 186 million miles (twice the radius of 93 million miles). Every six months, Bradley's telescope was 186 million miles from where he viewed the star the previous six months. Parallax seemed to place the star in slightly different positions. Bradley calculated that the aberration or movement he observed was related to the ratio of the velocity of light to the velocity of Earth as it circled the sun. He figured that this ratio was approximately 30 km s^{-1}, which is about 10,000 to 1. From this data he calculated that the speed of light was 3.083×10^8 m s^{-1}. This was the most accurate measurement for the speed of light at that time in history. Bradley's theory that explained the motion of Earth was the first direct evidence for such motion. Up until this time Earth's motion was always inferred from indirect factors.

Today, astronomers using the parallax concept can mathematically determine the distance of the closer stars to our solar system. Parallax does not work very well for distant objects located in deep space. Bradley also was one of the first to conceptualize that light has a finite, not infinite, speed. The idea of light having a finite speed (~186,000 miles per sec.), and the movement of Earth, were important concepts for compiling accurate observations and calculations of stars.

Bradley determined that Earth had a "wobble" (precession) as it spins on its axis. He also calculated the extent of this wobble on the changing gravitational attraction of the moon, which has a slightly inclined orbit around Earth.

See also Brahe; Copernicus; Galileo; Kepler

BRAHE'S THEORY OF THE CHANGING HEAVENS: Astronomy: *Tycho Brahe* (1546–1601), Denmark. (*Tycho Brahe* is the Latinized form of his birth name, Tyge Ottesen Brahe. Universally, he is referred to as "Tycho.")

> *Because a new star does not exhibit any parallax and comets come and go, there must be changes in the heavens, proving Earth with its orbiting moon is the center of the universe.*

Tycho Brahe was an ardent proponent of Ptolemy's concept that Earth was the center of the universe, but he did not accept the idea that the universe was static. Based on his observation, Tycho devised this theory of a changing universe but incorrectly believed Earth was at its center. Tycho's concept of a changing universe was unique; until that time Artistotle's concept of a

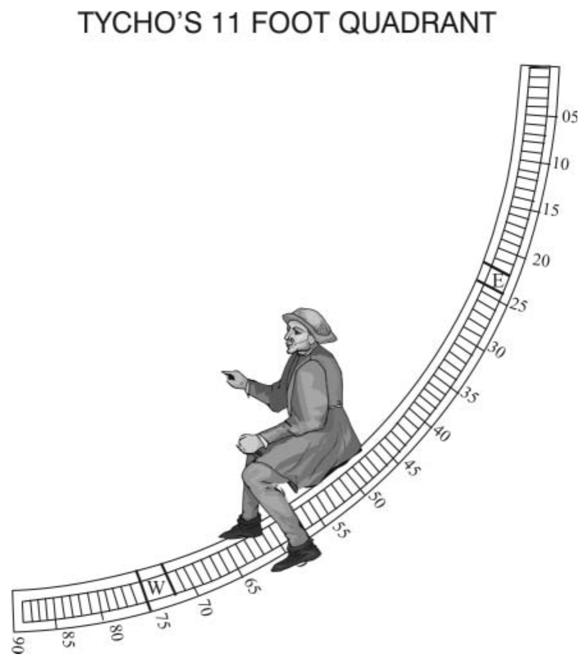


Figure B7. Tycho Brahe's 11-foot quadrant is an example of the large-scale astronomic instruments (sextants and quadrants) that he constructed for direct viewing since the telescope had not yet been invented. Some were so large that he was able to climb into them while viewing the heavens.

In 1577 Denmark's' King Frederick II offered Tycho Brahe unlimited funds and the use of the island of Hven for Tycho's lifetime if he would build his proposed observatory that would be large enough to hold Tycho's extra-large instruments for viewing the heavens. These included his large quadrants and sextants that enabled him to observe, with the unaided eye, and with some accuracy events outside of the solar system. This led to the development of his theory. After the death of Frederick II in 1588, his successor, Christian IV, became the king of Denmark. Christian IV and Tycho had a falling out, and Tycho was forced to find a new patron. He succeeded when he met someone a bit more unbalanced than himself, the Holy Roman Emperor Rudolph II, who gave Tycho another castle near the city of Prague to house his enormous instruments. He also acquired a young assistant, Johannes Kepler, who later made a name for himself. They did not get along, but their work was outstanding, and after Tycho's death two years later Kepler made good use of the mass of data Tycho had recorded.

An interesting story about Tycho Brahe's eccentric and argumentative nature related to the duel he fought when he was just nineteen years old. The dispute with a Danish nobleman was about who was the better mathematician. During the fight with swords Tycho lost the end of his nose. It is said that he then formed a false nose out of wax, gold, and silver that he wore for the rest of his life.

permanent, unchanging universe was accepted as fact. This belief changed when Tycho discovered a new supernova (exploding star) known as the "Tycho Star" in 1572. Tycho also discovered a large comet in 1577 that further supported his theory. A large crater on the moon is also named after him. Tycho's theory of a changing universe was not well accepted by other astronomers.

Because telescopes had not yet been invented, Tycho constructed several large sextants and quadrants for his direct sight viewing of the universe. He kept a journal of all his activities as well as astronomical tables, which later proved useful to his assistant, Johannes Kepler. Tycho's most important contribution was the result of the twenty years he spent recording the positions of over eight hundred stars that proved invaluable for the future work of Kepler. These records assisted Kepler in developing his three laws of planetary motion.

See also Copernicus; Galileo; Kepler; Ptolemy

BUFFON'S THEORIES OF NATURE: Biology: *Comte George Louis Leclerc de Buffon* (1707–1788), France.

Buffon's theory of ecology: *The animals of an area (ecology) are the product of the environmental conditions of the land where they developed.*

Comte de Buffon based this theory on his concept that Earth makes and grows the plants on which the animals depend; thus the region's plants determine the geography and geology of the region's animals.

Buffon's theory of natural classes: *Animals were classed not according to genera and species, but rather in a hierarchy of man, domesticated animals, savage animals, and lower animals.*

Taxonomy and species classifications based on structure and functions were not yet fully developed. Therefore, Buffon classed animals according to major categories as he interpreted their status in life. His classification of animals is somewhat similar to Aristotle's "ladder of life" (*see* Aristotle).

Buffon's theory of species: *Animals within a hierarchical group (species), and only those within that group, can reproduce themselves.*

Buffon based his theory on empirical evidence. He observed that animals of one group from his hierarchical classification of animals would breed only with others of their kind. He was unaware of hybrids or mutations.

Buffon's theory of the age of Earth: *Based on a series of stages as evidenced by geological history, Earth is seventy-eight thousand years old.*

Buffon rejected biblical records that contended Earth's age as six thousand years. His estimate of the age of Earth was based on fossils and geology. Buffon believed Earth was originally a hot body that cooled off sufficiently enough for people to exist and would continue to cool, at which time all life on Earth would end. His extension of the age of Earth led other scientists to examine fossils and geological evidence more closely, which provided a more accurate estimate of Earth's age. Today, the universe is considered to be ~13.4 to ~15 billion years old, with Earth being formed about ~3.5 to ~4.5 billion years ago.

Buffon's theory of the origin of the planets: *The formation of planets was the result of a collision between a large comet and the sun.*

Buffon is credited with providing an important naturalistic history of Earth. He based his concept of the origin of the **solar system** and planets on the more current explanation of natural forces where cosmic "dust" circulated to form the solar system and coalesce into the planets around the sun. He used the mechanics of motion as described by Sir Isaac Newton as well as his own empirical observations.

See also Cuvier; Darwin; Wallace

Buffon produced numerous writings that influenced other scientists for close to one hundred years. Some of his more famous publications were a translation of Hale's *Vegetable Statistics* (1735) and a translation of Newton's *Method of Fluxions* (1740). From 1740 to the end of his life Buffon worked on a massive forty-four volume manuscript titled *Histoire naturelle*, that included the following:

Volumes I–15 titled *Quadrupeds* (1749–1767)
Volumes 16–24 titled *Birds* (1770–1783)
Volumes 25–31 titled *Epochs of Nature* and *Supplementary Volumes* (1778)
Volumes 32–36 titled *Minerals* (1783–1788)
Volumes 37–44 titled *Reptiles* (including *fish* and *cetaceans*) (1788–1789).

His most influential work was included in Volume I with the subtitle of *Preliminary Discourse of Nature* where his ideas were ahead of his time, nontheological, and very rational but were not always correct. He proposed the division of animals into natural classes, while insisting that only individual species existed in nature and that only two animals of the same species can propagate themselves.

BUNSEN'S THEORY OF THE SPECTROCHEMISTRY OF ELEMENTS: Chemistry: *Robert Wilhelm Bunsen* (1811–1899), Germany.

Each element, when heated, emits a unique electromagnetic spectrum that can be identified by careful spectrum analysis of the emitted light.

While assisting in an experiment of spectrum analysis, Robert Bunsen, along with his assistant, Peter Desaga, refined Michael Faraday's gas burner by adding a collar that could be adjusted to control the flow of air into the burning gas. This device greatly improved the burner by providing a hotter and steady flame. Since that time, it has been known as the *Bunsen burner*. By using this extremely sensitive instrument (spectroscope) other scientists were able to identify and discover new elements. Bunsen is credited with the discovery of two new elements: rubidium and cesium.

By using the spectra produced by different elements Bunsen and Gustav Kirchhoff are credited with providing the first evidence for the internal structure of atoms that make up all matter. Up to this time it was believed that the "atomic" nature of the structure of the different elements was invisible. The use of his concept that each element has it own unique frequency (wavelength) that can be detected by using his spectroscope was applied to astronomy. Astronomers, using this device, were able for the first time to analyze the light from the stars from which they were able to detect the various chemical elements that composed the stars, including our sun. In addition to the field of **spectroscopy**, Bunsen contributed to the fields of electrochemistry, electrodeposition of metals, and photochemistry.

His career began by experimenting in organic chemistry. The results of his work were published between the years of 1837 to 1842 in *Studies in the Cacodyl Series*. While experimenting with the toxic compounds of cacodyls (tetramethylarsine, a derivative of arsenic), he lost an eye in an accidental explosion. He also nearly killed himself by arsenic poisoning as he worked with poisonous compounds of arsenic, chlorine, fluorine, and cyanide. He soon changed the direction of his work and began experimenting with inorganic compounds, spectroscopy, and electrochemistry. In cooperation with Gustav Kirchhoff, he published the *Chemical Analysis through Observations of the Spectrum* in 1860. His contributions in this field were made possible by the improvement of Michael Faraday's gas burner that he completed in 1855.

See also Berzelius; Faraday; Kirchhoff

THE B_2FH (BURBIDGE–BURBIDGE–FOWLER–HOYLE) THEORY: Astronomy: *Eleanor Margaret Burbidge*, *née Peachey* (1922–) along with her husband *Geoffrey Burbidge* (1925–) were the lead researchers of this group that included *William Fowler* and *Sir Fred Hoyle*, England and United States.

The theory is known as the B_2FH theory of the formation of chemical elements in the universe. It states: *Chemical elements are produced in the nuclei of stars of during supernova explosions*.

The Burbidges along with Fred Hoyle of Great Britain and William A. Fowler of the United States published the B_2FH theory in 1957. It explained how all the lighter elements from hydrogen to iron began with hydrogen. However, the original theory had some "gaps" that needed to be explained. One problem in their theory was that if all the elements were produced by either supernova explosions or inside stars, the great abundance of helium and deuterium (heavy hydrogen) in the universe could not be explained. George Gamow and other scientists proposed another theory that states that in the very early period after the big bang, all matter was ionized and dissociated forming a type of plasma. In just a few minutes the temperature dropped, resulting in **nucleosynthesis**, at which time a few light elements were created. Protons and neutrons were formed within the first three minutes after the big bang. They collided with each other to produce deuterium (heavy hydrogen), which consists of one proton and one neutron. Then deuterium nuclei collided with additional protons and neutrons to create helium as well as the next element in the periodic table, that is, lithium nuclei consisting of a mass of a total of seven protons and neutrons (which is a combination of one tritium [$_3$H] and two deuterium [2_2H] nuclei). The fact that helium makes up about 25% of all the mass in the universe is evidence that a very hot phase existed shortly after the big bang. Later it was theorized that the heavier elements were created by the fusion reaction within stars. Margaret Burbidge is one of the outstanding women in science and astronomy who can be claimed by England and the United States. She received many academic and scientific honors later in her life.

Margaret Peachey-Burbidge began her career at the University of London where she graduated in 1948. She then joined the University's Observatory and after receiving her PhD served as its acting director from 1950 to 1951. From this position she moved to the Yerkes Observatory at the University of Chicago in 1951 to 1953, followed by research work at the California Institute of Technology from 1955 to 1957. She also did research work at the Cavendish Laboratory in Cambridge, England, before returning to the Yerkes Observatory at Chicago where she served as associate professor of astronomy from 1959 to 1962, at which time she moved to the University of California at San Diego as professor of astronomy from 1964 to 1990. Her career was briefly interrupted when, on a leave, she returned to England to become the director of the Royal Greenwich Observatory where she made improvements in optical astronomy in England. The Royal Observatory located in Greenwich, London, was founded by King Charles II in 1675 and provided astronomical services until 1946. In 1946 the Royal Observatory was moved to the Herstmonceux Castle in Sussex, England. Because this region was located close to the ocean and near sea level, it provided poor viewing conditions for optical telescopes. Also, the castle was very old and in need of many repairs. The castle became a hotel that did not survive and is now a science center. Administration operations, except the telescopes and other equipment, were moved to Cambridge, England, in 1990. After her marriage to the theoretical physicist Geoffrey Burbidge the couple collaborated with other astronomers and physicists to study the physical nature of how chemical elements are synthesized in stars.

See also Fowler; Gamow; Hoyle

C

CAGNIARD DE LA TOUR'S CONCEPT OF "CRITICAL STATE": Physics: *Charles Cagniard de la Tour* (1777–1859), France.

> *The critical state exists at the point where the temperature and pressure create equal densities between a liquid and its vapor. The vapor and liquid can be in equilibrium at any temperature that is below the critical point.*

The term "critical state" is also known as *critical point* (at the critical temperature there is no clear-cut distinction between the vapor [gas] and liquid states) (*see* Figure B5 under Black). Their densities are equal, and their two phases are also equal and considered to be one phase. Cagniard de la Tour Cagniard discovered the concept of the *critical state* in 1822 by heating liquids in a sealed tube until the liquid and vapor were not distinguishable from each other. He referred to this point as the **critical temperature**. His concept was based on the work of the French physicist Louis Paul Cailletet, the English physicist James P. Joule, and the Irish chemist and physicist Thomas Andrews (1813–1885).

Some examples of practical applications are boilers used in home heating and industry, steam engines, and frequently in the generating of electricity by steam turbines. Another example is the pressure cooker. By increasing the pressure, the liquid and vapor can be compressed with an increase in temperature, changing the critical state until pressure is released. Food then cooks faster under the increased pressure, using less applied heat than nonpressurized cooking.

Cagniard is also known as the inventor of the siren used on police cars, fire engines, and so forth to produce a rising, piercing sound. He formed a disk containing one or more holes, and when the disk was spun rapidly and air was passed through the holes in the disk, the typical siren sound was produced. His original, crude apparatus has undergone many improvements in the last century and a half.

See also Cailletet; Joule; Kelvin

CAILLETET'S CONCEPT FOR LIQUEFYING GASES: Physics: *Louis Paul Cailletet* (1832–1913), France.

As pressure on most gases increases, so does the boiling point. Therefore, reducing the temperature while increasing the pressure will liquefy the gas at a lower pressure.

After studying in Paris, Cailletet returned home to assist his father in his ironworks business. He became interested in metallurgy, particularly in the use of forced air applied to the blast furnace. This led him to try to liquefy gases, such as hydrogen, oxygen, and nitrogen that would then be more easily transported to blast furnaces. He failed in this attempt, which led him to identify H_2, O_2, and N_2 as *permanent gases*. It was at this point that he learned about the works of other physicists regarding the concept of critical temperature (*see* Cagniard). This concept gave him the idea that it would require more cooling of his gases as well as greatly increasing the pressure (then releasing the pressure) for the gas to become cool enough to liquefy. This idea is based on the Joule–Thompson effect, which in effect means that when a gas expands, its temperature decreases. Cailletet was the first to liquefy his "permanent gases" by compressing oxygen, hydrogen, nitrogen, and air by rapidly increasing the pressure, and then releasing the pressure of cold gases, which further reduced the temperature by the rapid expansion of the gas. Thus, the gas reached the critical temperature point at which gaseous air turned into liquid air. This process is used today to produce various liquefied gases including air from which other gases are fractionated (e.g., oxygen and nitrogen) that are used in experimental work in nuclear physics, chemistry, and cryogenics. Compressed and liquefied oxygen is essential in the health care of oxygen-dependent patients and in many industrial processes, such as steel production, smelting, rocket fuels, and welding.

Cailletet was also ahead of his time in considering high-altitude flight. He invented the **altimeter,** the **manometer**, and a mask-like breathing device that could be used at high altitudes.

See also Cagniard; Joule; Kelvin

CALVIN'S CARBON CYCLE: Chemistry: *Melvin Calvin* (1911–1997), United States. Calvin was awarded the 1961 Nobel Prize in Chemistry.

The path (route) of carbon dioxide in the chemical and physical reactions of photosynthesis occurs only in the presence of chloroplasts of living plants.

Melvin Calvin began his teaching at the University of California, Berkeley, in 1937. During World War II he worked on the Manhattan atomic bomb project where he conducted research that involved new analytical techniques. He spent the remainder of his career at the University of California where he applied the techniques of ion-exchange chromatography and the use of radioisotopes to the study of **photosynthesis**.

Photosynthesis takes place in green plants when they are exposed to sunlight by absorbing carbon dioxide (CO_2) from the atmosphere and by an intricate process that converts the CO_2 molecules into starch and oxygen (O_2). This process sends oxygen into the air at about 10^{12} kilograms per year on Earth. It is believed that photosynthesis is responsible for supplying the oxygen in the atmosphere of the ancient Earth that enabled primordial life to begin many millions of years ago.

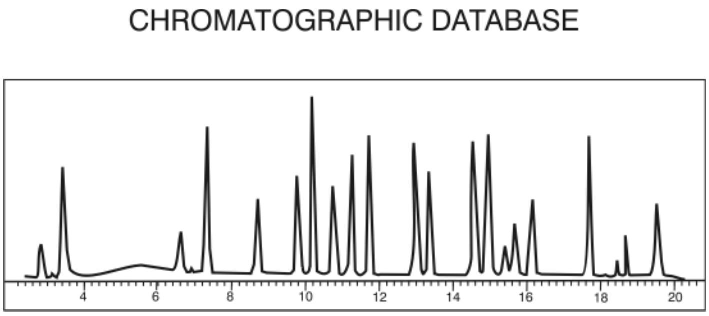


Figure C1. Results from a typical chromatography analysis.

Calvin exposed plants for a few seconds to radioactive CO_2 containing the isotope carbon-14. Carbon-14 has the same atomic number (six protons) and is chemically similar to carbon-12, the more abundant form of carbon. But the carbon-14 nucleus has two more neutrons than the nucleus of C-12. There is no chemical distinction between C-14 and C-12 because they have the same atomic number (number of protons). The radioactive tracer of C-14 was assimilated in plant chloroplasts during the process of photosynthesis and could be traced with radiation detection devices. Because the process is very rapid, he worked quickly to mash the cells to separate the carbon-14 in boiling alcohol. He then separated and identified the components and products of photosynthesis by using paper chromatography. After many experiments, Calvin identified the cycle of absorption and the use of carbon dioxide by plants, leading to a better understanding of the roles of chlorophyll and carbon dioxide in the science of photosynthesis.

Using this technique Calvin identified the cycle for the reductive pentose phosphate reaction that is an important aspect of photosynthesis. This is now known as the "Calvin cycle" for which he won the Nobel Prize.

We now know that most plants increase their rate of growth in an atmosphere rich in CO_2. Carbon dioxide is sometimes added to the inside air in greenhouses to accelerate plant growth. An increase in the growth rate of crops is one of the few benefits of the excessive production of carbon dioxide in modern society. Calvin is also known for his development of the analytical techniques that use radioisotopes for labeling stages in chemical and physical reactions as well as in chromatography methods. They are all important analytical processes used in today's laboratories.

CANDOLLE'S CONCEPT OF PLANT CLASSIFICATION: Biology: *Augustin Pyrame de Candolle* (1778–1841), Switzerland.

> *There is a homologous or fundamental relationship of similarities for the parts of different types of organisms.*

Several classification systems for plants and animals existed at the time of Candolle's work. However, Candolle was the first to use the terms "taxonomy" and "classification" synonymously. His taxonomy (naming system) was based on the recognized similarity of various body parts of near relatives of different species, thus assuming they derived from common ancestors. Candolle also originated the idea of **homologous** parts, which

After studying medicine in Geneva, Switzerland, Candolle went to Paris, France, to study natural sciences as well as medicine. He met and was influenced by several naturalists, including Georges Cuvier and Jean Lamarck, and soon became better known as a botanist than a medical doctor. His many scholarly papers earned him a reputation that resulted in an assignment to conduct a botany and agricultural plant survey of France. In 1813 he published his first original volume titled *Elementary Theory of Botany.* Based on the natural classification systems of Cuvier and other botanists, Candolle introduced, for the first time, the concept of taxonomy as related to classification. Candolle's taxonomy form of classification took the place of the older Linnaeus system and was used for about fifty years before other botanists improved it. Candolle also was the first to realize that geographic location, to some degree, determined what plants were native to a particular region. His concept was based on the premise that various types of soil found in different geographic regions determined the types of vegetation growing in a specific region.

Between 1824 and 1839 Candolle wrote a massive seventeen-volume encyclopedia titled *A Guide to Natural Classification for the Plant Kingdom.* He was only able to publish the first seven volumes before his death; his son completed the publication of the remaining ten volumes after his father's death in 1841.

along with the concept of relating taxonomy to species influenced the British naturalists Alfred Wallace and Charles Darwin in the development of their theories or organic evolution. Only six volumes of Candolle's twenty-one-volume taxonomy project were published before his death. His work, which was superior to that of Carolus Linnaeus, is still used today.

See also Cuvier; Lamarck; Linnaeus

CANNIZZARO'S THEORY OF ATOMIC AND MOLECULAR WEIGHTS: Chemistry: *Stanislao Cannizzaro* (1826–1910), Italy. In 1891 the Royal Society of London awarded Cannizzaro the Copley Medal for his contributions to science.

> *The atomic weights of elements in molecules of a compound can be determined by applying Avogadro's law for gases, which states that gram-molecular weights of gases occupy equal volumes at standard temperature and pressure (STP).*

In essence, Avogadro's law states that all gases that are at the same pressure and temperature will contain the same number of molecules. Cannizzaro's genius was recognizing the utility of this law fifty years after it was proposed by Avogadro and ignored by other scientists. Cannizzaro applied the law as a means for measuring the atomic weights of atoms of elements and the weights of gas molecules. He also determined that the theory could be applied to solids if their vapor density is unknown by measuring their specific heat. Although Cannizzaro credited Avogadro for the basis of his theory, it was Cannizzaro in his 1858 publication *The Epitome of a Course of Chemical Philosophy* that finally convinced the scientific community that molecular weights of gases could be determined by measuring their vapor densities. In essence, Cannizzaro restated Avogadro's theory that definitely established the theory of atoms and molecules in a way that was accepted by the chemists of his day. The field of quantitative chemistry rapidly advanced once atomic and molecular weights could be accurately determined. Cannizzaro's theory provided a means for defining the molecular weights of many organic compounds, as well as clarifying the structure of complex organic molecules. Avogadro's number of molecules in a gram-molecule weight of gases at standard conditions has been determined experimentally as 6.02×10^{23} and is now considered Avogadro's constant.

See also Avogadro

CANTOR'S MATHEMATICAL THEORIES: Mathematics: *Georg Ferdinand Ludwig Philipp Cantor* (1845–1918), Germany.

Cantor's theory of infinity: *Without qualification, one can say that the transfinite numbers stand or fall with the infinite irrational; their inmost essence is the same, for these are definitely laid-out instances or modifications of the actual infinite.*

This theory is related to Cantor's axiom, which states that if you start with a single point on a two-dimensional surface and continue to add points on each side of the original point, they will continue to extend out in both directions. By adding point-to-point, there will be no one-to-one relationships between the two directions of points, and the lines they form can be extended forever (infinity). Another way to look at this is as follows. If you start from zero, you can progress indefinitely to larger and larger functions, or you can extend indefinitely in the opposite direction to smaller and smaller values.

Cantor's set theory has a long history although it was essentially created by one person—George Cantor in the late 1800s. The theory's history goes back as far as the Greek philosopher, Zeno of Elea, in ~450 BCE. Since then, ideas related to infinity and cardinal numbers, imaginary numbers, algebra, groupings, classifications, and so on have all led up to Cantor's theory. In mathematics a "set" can be a collection of distinct objects that are considered as a whole (the parts comprise the whole). Although this seems a simple idea, some mathematicians did not accept it. Today it is a fundamental concept in modern mathematics and is now taught at the grade school level. Cantor's concept was that the objects (things) in the set, which are called elements of the members of the set, can be anything such as numbers, pencils, shoes, letters of the alphabet, and so on. Sets are designated by using capital letters (A, B, C, etc,). Two sets of things, A and B are said to be equal if they have the same members (an element or things in each set). A set in mathematics is not the same as what is thought of as a set in real life. In real life it is possible to have a set of something that has multiple copies of the same element (things or objects), whereas in mathematics if two different sets have the same members or items, they are equal even if the members are not in the same order. For instance; Cantor proved that if A and B are sets with A being equivalent to the subset of B, and B is equivalent to a subset of A, then A and B are equivalent. Over the years the mathematical theory of sets and subsets has been refined, and set theory is a fundamental mathematical concept.

Karl F. Gauss, the German physicist and mathematician, stated that infinity was not permitted in mathematics and was only a "figure of speech." The concept of endlessness, whether in time, distance (space), or mathematics, is difficult to grasp. Galileo considered the study of infinity as an infinite set of numbers, later defined as Galileo's paradox. However, it was not until Sir Isaac Newton and Gottfried Leibniz developed calculus that it became necessary for a mathematical explanation of infinity. The English mathematician John Wallis (1616–1703), who developed the law of conservation of momentum, also proposed the symbol for infinity (∞), which was known as the "lazy eight" or "love knot." It was Georg Cantor, however, who postulated that consecutive numbers could be counted high enough to reach or pass infinity. His development of transfinite numbers, a group of real numbers (rational and irrational) that represent a higher infinity, led to *set theory*, which permits the use of numbers within an infinite range.

Cantor is better known for his proposed set theory: *The study of the size (cardinality) of sets of numbers and the makeup or structure (countability) of groups of rational or irrational natural numbers.* Following are two examples of sets of numbers:

$$\begin{array}{cccccl} 1 & 2 & 3 & 4 & 5,\text{–.–.–.–}, & n,\text{–.–.–.–}, \infty \\ \updownarrow & \updownarrow & \updownarrow & \updownarrow & \updownarrow & \\ 2 & 4 & 6 & 8 & 10,\text{–.–.–.–}, & 2n,\text{–.–.–}.\ \infty \end{array}$$

1 2 3 4 5,–.–.–.–, n, –.–.–.–∞
↕ ↕ ↕ ↕ ↕
1 4 9 16 25,–.–.–.–, n^2,–.–.–.–, ∞

Where *n* is a continuation of the sequence or set. By finding a one-to-one match in a set (in the example, a number below the number above it), even if the set is infinite, it is possible to determine the size of the number if the entire structure is unknown. If the set is infinite, some of the numbers can be eliminated without reducing the size or eliminating the structure of the set.

See also Galileo; Gauss; Leibniz; Newton

CARDANO'S CUBIC EQUATION: Mathematics: *Gerolamo Cardano* (1501–1576), Italy.

Definition of cubic equation: *A polynomial equation with no exponent larger than three—Specifically:* $x^3 + 2x^2 - x - 2 = 0\ (x - 1)(x + 1)(x + 2)$, *which can be further treated by algebraic functions.*

Earlier mathematicians solved equations for x and x^2 but were unable to solve x^3 (cubic) equations. (First-degree equations are linear [straight line], or one-dimensional, involving x; second-degree equations are quadratic [plane surface], or two-dimensional, involving x^2; and third-degree equations are cubic [solid figures], or three-dimensional, involving x^3.) The graphic depiction for the solution of a cube is usually easier to understand than is the algebraic representation. When a graph is used to solve cubic equations, the x-axis is eliminated and reoriented. Cardano was not the first to come up with a solution to cubic equations, having been given the explanation for cubic and biquadratic equations by the Italian mathematician and engineer Niccolo Tartaglia who made Cardano promise not to reveal the secret. After Cardano found that someone previous to Tartaglia had achieved a partial solution, he published the results as his own version. As the first to publish, Cardano has been credited with the discovery of a solution to solving cubic equations. As a result of this controversy, a new "policy" stated that the first person to publish the results of an experiment or a discovery, and not necessarily the first person to actually conduct the experiment or make the discovery, is the one given credit. This is based on the belief that science should be open and available to all rather than kept secret.

See also Tartaglia

CARNOT'S THEORIES OF THERMODYNAMICS: Physics: *Nicholas Leonard Sadi Carnot* (1796–1832), France.

Carnot cycle: *The maximum efficiency of a steam engine is dependent on the difference in temperature between the steam at its hottest and the water at its coldest. It is the temperature differential that represents the energy available to produce work.* $T_2 - T_1 = E$, *where* T_2 *is the higher temperature,* T_1 *is the lower temperature, and E is the energy available to do work. The efficiency E is 1 only if* $T_1 = 0$ *Kelvin.*

The concept of a temperature differential is analogous to the potential energy of water flowing over a water wheel to produce work. This concept enabled inventors to develop more efficient steam engines and locomotives and became known as the Carnot cycle, based on the difference in the temperature of the steam at its highest temperature and the water at its coldest temperature—not on the total amount of internal heat. Carnot pointed out that energy (heat) is always available to do work, but it cannot completely be turned into useful work. Even so, it is always conserved; none is ever "lost." For example, within the steam engine, which is not 100% efficient, some energy is not available to accomplish work due to "lost" heat. The first law of thermodynamics (the word *thermo-dynamics* means "heat-flow" in Greek) states that energy is always conserved, while the second law states there is a limit to how much of the energy can be converted into work. A system cannot produce more energy (work) than the amount of energy that is expended. Perpetual motion is impossible, as some energy is always lost to heat due to friction.

See also Clausius; Fourier; Helmholtz; Kelvin; Maxwell

CASIMIR FORCE (EFFECT): Physics*: Hendrick Brugt Gerhard Casimir* (1909–2000), Netherlands.

> *The Casimir force is the effect of a very small attraction that takes place between two closely spaced plates that, although they have the ability to carry an electrical charge, are uncharged in an environment of a quantum vacuum that contains virtual particles that are in continuous motion.*

These two plates may be composed of a conductor (any substances such as metals that can carry an electrical current), or a dielectric (a substance other than a metal on which an electrical field might be sustained with the loss of minimum power, i.e., insulator).

Casimir's two electron theory: *During superconduction there are pairs of electrons consisting mostly of normal electrons, but some are superconducting electrons.*

Along with the assistance of two colleagues, the German physicist Walther Meiβner and the Dutch physicist Cornelis Gorter (1907–1980), in 1934 Hendrik Casimir explained their "two fluid" model of superconductivity at low temperatures. At near absolute zero some properties of superconductivity are altered. Two types of electrons are formed, most were normal-type electrons and a few were types of superconducting electrons. This explained the physics between the thermal and magnetic properties of superconductors. These electrons form types represented by paired and unpaired electrons referred to as "Cooper pairs."

The Casimir force provided evidence for the concept of a quantum vacuum, which is similar in quantum mechanics to what is described as empty space in classical physics. It is due to quantum vacuum changes in the electromagnetic field between the plates. The Casimir force also proved the viability of the *van der Waals force* that exists between two uncharged atoms (not ions). In addition, the Casimir force affects the ***chiral bag*** (nonmirror image) asymmetric model

> An interesting analogy of the Casimir force was evident as far back as the 1700s when sailors observed that when two large wooden ships came closer than 50 feet to each other side-by-side, a calm sea would form between the ships. This "calm" would occur between the ships regardless of how high the waves were on the open ocean side of the ships. As the distance between the ships decreased, they were drawn closer together by the Casimir-like force. If the ships were not forcefully separated, they would soon crash into each other. The solution was to send small boats full of sailors to forcibly keep the ships apart.
>
> A more recent application of the Casimir force is in the field of applied physics (engineering) in the development of the science of **nanotechnologies** where exotic materials are artificially constructed at the atomic and molecular levels.

of the nucleon, which indicated that the mass of the nucleon is independent of the bag radius. Also, the Casimir effect needs to be considered in the field of extremely small electro-mechanical systems including the design of computers and cell phones.

See also Meissner; Van der Waals

CASPERSSON'S THEORY OF PROTEIN SYNTHESIS: Chemistry: *Torbjorn Oskar Caspersson* (1910–1997), Sweden.

Proteins are synthesized in cells by large RNA (ribonucleic acid) molecules.

Torbjorn Caspersson invented a new type of spectrophotometer, enabling him to trace the movement of RNA. He concluded that RNA is involved in the synthesis of amino acids in the production of proteins. RNA is a type of single, long, unbranched, organic macromolecule responsible for transmitting genetic information to deoxyribonucleic acid (DNA) molecules (*see* Figure C5 under Crick). All organisms, except viruses, depend on RNA messengers to carry inherited characteristics to the DNA molecules, which can then be duplicated to pass genetic information to offspring. In RNA-type viruses, the RNA itself acts as the DNA because it contains all the genetic information required for the virus to replicate. Caspersson was the first to determine that DNA had a molecular weight of 500,000 **daltons**. In addition, he discovered a way to dye specimens of DNA so that the nucleotides would appear in dark bands. Caspersson's work provided information used by Crick and Watson in discovering the specific double helix shape of the DNA molecule.

Tests comparing one person's DNA with another person's or their offspring can determine who is genetically related to whom, often years after death. Many police departments and laboratories use this procedure to test and compare human DNA when investigating the crimes of rape and murder.

See also Chargaff; Crick

CASSINI'S HYPOTHESIS FOR THE SIZE OF THE SOLAR SYSTEM: Astronomy: *Giovanni Domenico Cassini* (1625–1712), France.

The mean distance between Earth and Sun is 87 million miles.

Giovanni Cassini developed this figure by working out the parallax for the distance of Mars from Earth, which enabled him to calculate the astronomical unit (AU) for the distance between Earth and the sun. He accomplished this by using calculations attained by other astronomers, as well as his own observations. The figure greatly increased the estimations at this time in history for the size of the solar system. In the late 1500s Tycho Brahe calculated the distance between Sun and Earth at just 5 million miles. A few years later Johannes Kepler's estimation of 15 million miles was better, but still greatly underestimated, whereas in 1824 the German astronomer Johann F. Encke (1791–1865) used Venus's transit with the sun to overestimate the distance as 95.3 million miles. (The correct mean distance from Earth to the sun's center is approximately 92.95 million miles = 1 AU.)

Cassini was the first to distinguish the major gap separating the two major rings of Saturn, now called the Cassini division. He also discovered four new moons of Saturn, determined the period of rotation of Jupiter as 9 hours, 56 minutes, and observed that Mars rotates on its axis once every 24 hours, 40 minutes. Cassini measured Earth's shape and size but incorrectly identified it as a perfect sphere. His work is convincing, inasmuch as Earth is not unique in the solar system and is similar to the other inner planets, with the obvious exception of its human habitation.

See also Brahe; Kepler; Spencer-Jones

CAVENDISH'S THEORIES AND HYPOTHESIS: Chemistry: *Henry Cavendish* (1731–1810), England.

Cavendish's theory of flammable air: *When acids act on some metals, a highly flammable gas is produced, called "fire air."*

Henry Cavendish was one of the last scientists to believe in the **phlogiston** theory of matter, which states that when matter containing phlogiston burns, the phlogiston is released. Because his "fire air" would burn, he called it *phlogisticated air*. It was Antoine Lavoisier who named the new gas *hydrogen*, meaning "water former" in Greek. Cavendish was the first to determine the accurate weights and volumes of several gases (e.g., hydrogen is one-fourteenth the density of air). Until this time, no one considered that matter of any type could be lighter than air (*see also* Lavoisier; Stahl).

Cavendish's theory of the composition of water: *When "fire air" and oxygen are mixed two to one by weight and are burned in a closed, cold, glass container, the water formed is equal to the weight of the two gases. Thus, water is a compound of hydrogen and oxygen.*

Although similar experiments and claims that water is a compound, and not an element (as believed for hundreds of years), were made by other scientists, Cavendish was credited with the discovery of hydrogen, as well as the concept of water as a compound, although he delayed publishing the results of his experiments.

Cavendish developed many concepts but had difficulty making generalizations from his experimental results. Two examples of his "new" discoveries are 1) the distinction between electrical *current*, *voltage*, and *capacitance*, which later led to Ohm's law, and 2) the anticipation of the gas laws dealing with pressure, temperature, and water vapor. He also foresaw the chemical concepts of multiple proportions and equivalent weights for which John Dalton and others were given credit. Cavendish also determined that oxygen gas has the same molecular weight regardless of where it is found and that the percentage of oxygen in ordinary air is approximately the same wherever found on Earth.

Cavendish's hypothesis for the mass of Earth: *Based on the determination of the gravitational constant and the estimated volume of Earth, its mass should be* 6.6×10^{36} *tons, with a density about twice that of surface rocks.*

Cavendish's procedure for determining the mass of Earth is known as the Cavendish experiment. It involved two large lead balls on the ends of a torsion bar and two small lead balls, one on each end of a single rod suspended at its midpoint by a long, fine wire. As the two large lead balls were brought close to the smaller ones from opposite directions, the force of gravity between the balls produced a minute twist in the wire that could be measured. From this twist, Cavendish calculated the gravitational force between the balls, which he used as a gravitational constant for calculating the mass of Earth. His figure was approximately 6,600,000,000,000,000,000,000 tons, very close to today's estimation of 5.97×10^{24} kilograms.

See also Dalton; Ohm

CELSIUS TEMPERATURE SCALE: Physics: *Anders Celsius* (1701–1744), Sweden.

A standard centigrade scale for measuring temperatures with 100 graduation points is needed for scientific endeavors using the metric system.

Invented in 1742, the Celsius temperature scale was originally referred to as the "centigrade" scale from about 1750 until the middle of the twentieth century because the apparatus that Anders Celsius used to boil water was zero and the freezing point was 100. Celsius' scale was the reverse of the modern centigrade (Celsius) scale now in use. The scale was based on 100 units and thus the prefix "centi" for the name of the scale. Its name was not officially changed to "Celsius" until 1948.

Celsius, a young mathematician became a professor of astronomy at Uppsala University in Stockholm, Sweden, where he built and then became the director of an observatory in 1740. He devised his new temperature scale in 1742 that is now the most-used scale throughout the world, not just in science. However, he was not the first to arrive at some type of scale for recording temperatures. Others before, as well as after Celsius, included Daniel Fahrenheit, Lord Kelvin, Christian of Lyons (fl. 1743), William Rankine (1820–1872), Joseph-Nicolas Delisle (1688–1768), Carolus Linnaeus, Per Elvius the Elder (1660–1718), Isaac Newton, Rene-Antoine Reaumur (1683–1757), and Ole Römer.

The Celsius temperature scale was originally based on the freezing point of water as being 100 on the scale and the boiling point of water at 0 degrees, assuming the conditions of standard atmospheric pressure. It was not until after Celsius' death in 1744 at the age of forty-two that the scale was reversed to represent the temperature of boiling water at $100^{\circ}C$ and the freezing point of water at $0^{\circ}C$, where it remains to this day.

The temperature at which all molecular motion ceases (except vibrations of individual particles/molecules) is now referred to as absolute zero, which is 0 degrees on the Kelvin scale. The boiling point on the Fahrenheit scale is 212 and the freezing point is 32. The Fahrenheit scale is only used in two countries of the world, the United States and Myanmar (formerly Burma) (*see also* Farhrenheit; Kelvin).

The conversion formulas used to change one scale to another follow:

1. Celsius to Fahrenheit: Conversion Formula: $F = C \times 1.8 + 32$.
2. Fahrenheit to Celsius: Conversion Formula: $C = (F - 32) / 1.8$.
3. Celsius to Kelvin: Conversion Formula: $K = C + 273.15$.
4. Kelvin to Celsius: Conversion Formula: $C = K - 273.15$.

CHADWICK'S NEUTRON HYPOTHESIS: Physics: *Sir James Chadwick* (1891–1974), England. Chadwick was awarded the 1935 Noble Prize for Physics.

Physicists believed there were only two elementary particles in atoms: the positive proton and the negative electron. However, this concept was not adequate to explain many physical phenomena. One idea was that the internal nucleus of a helium atom has four protons, as well as two internal neutralizing electrons, which could explain the 2+ charges for helium. But scientists could not identify any electrons originating from the helium nuclei when it was bombarded with radiation. Another dilemma was that nitrogen has a mass of 14 but an electrical charge of 7+. This was confusing because if the nitrogen nucleus has 14 protons, it would have a charge of 14+. One solution was to assign seven negative electrons to neutralize seven of the positive protons, meaning the nucleus of nitrogen now has twenty-one particles. Because this did not make sense to many scientists, it was determined that the measured "spin" of particles in the nitrogen nucleus could be only a whole number; thus there could not be twenty-one particles in the nucleus. Further work demonstrated that gamma rays did not eject the electrons from positive protons, nor did the radiation eject the protons. Therefore, it was hypothesized that some new particle(s) with no electrical charge and very little mass must exist in the nuclei of atoms. Some years later this "ghost particle" was found and named the *neutrino* (*see also* Fermi; Pauli; Steinberger).

Chadwick's hypothesis: *Particles with the same mass as protons, but with no electrical charge, were one of the particles ejected from helium nuclei by radiation.*

There was some opposition to Chadwick's construction of a cyclotron type of instrument by the British-based New Zealand physicist Baron Rutherford who thought it might lead to uncontrolled release of energy. This argument led Chadwick in 1935 to move from the Cavendish Laboratory in London to the physics department at Liverpool University. While chair of the physics department at Liverpool, he built the first cyclotron in Great Britain that produced results that supported the claims of Otto Frisch that a sustainable chain reaction is possible by the fission of a few pounds of Uranium-235, and Rudolph Peierls' concept that it was possible to separate fissionable Uranium-235 from a much larger quantity of Uranium-238. Frisch and Peierls believed that the atomic bomb was possible by releasing enormous amounts of energy by the process of the fission of nuclei. At the outbreak of World War II Chadwick moved to the United States as head of the British group working on the Manhattan Project that developed the first sustainable nuclear chain reaction. In 1945 Sir James Chadwick was knighted for his contributions in the field of physics and his service during World War II.

In the early twentieth century Walther Bothe bombarded beryllium nuclei with alpha particles (helium nuclei) and detected some unidentified **particle** radiation. Chadwick continued this work and called these nuclear particles *neutrons* because they carried no electrical charge but had a similar mass as protons. This discovery assisted in understanding the atomic number and the atomic mass of elements and provided an excellent tool for further investigations of the structure of atoms. It was this discovery for which Chadwick was awarded the 1935 Nobel Prize in Physics. Neutron bombardment is used today to produce **radioisotopes** for medical purposes. Chadwick also was the developer of the first **cyclotron**, or "atom smasher," in England. Some physicists consider Chadwick's neutron discovery the beginning of the nuclear age because it led to understanding the physics necessary to develop practical uses for nuclear fission such as nuclear energy used in electric power plants and the atomic fission bomb and nuclear **fusion** hydrogen bomb.

See also Anderson (Carl); Fermi; Heisenberg; Pauli; Soddy

CHAMBERS' THEORY OF THE ORIGIN OF LIFE: Biology: *Robert Chambers* (1802–1871), Scotland.

> *If the solar system can be formed by inorganic physical processes without the assistance of a supreme being, then it follows that organic plants and animals can develop by a similar physical system.*

In other words, if the formation of an inorganic world (the universe) is possible without intervention of a supreme entity, then an organic world is also possible.

Robert Chambers was self-educated by reading the *Encyclopedia Britannica* and other science publications. He published several books while in partnership with his brother, William, after they established their own publishing house, which is still in business in Edinburgh, Scotland. He wrote extensively on the origin and development of the solar system and proposed that the organic world operated on the same principles as the inorganic world. He wrote that there was a progression from lower animals to higher life forms with no input by a god. The force responsible for life was based on his concept of chemical/electrical interactions.

A contemporary of Charles Darwin, Chambers based his theory for the origin of life on his acceptance of Pierre Laplace's nebula hypothesis for the origin and stability of the solar system. Many scientists accepted as a logical explanation Chambers' concept that the same laws of physics and chemistry that created the universe could create organisms. But theologians and the general public never accepted it because the theory denied credit for the origin of life to a supreme being (deism) or personal god (theism). Chambers proposed several other theories related to the embryonic development of species, which engendered tremendous negative reactions from the public.

See also Baer; Haeckel; Laplace; Ponnamperuma; Swammerdam

CHANDRASEKHAR LIMIT: Astronomy: *Subrahmanyan Chandrasekhar* (1910–1995), India.

The Chandrasekhar limit is a physical constant that states *if white dwarf stars exceed a mass of 1.4 greater than the sun's mass, they will no longer be self-supporting. As their mass increases past this limit, internal pressure will not be balanced by the outward release of pressure generated by atoms losing electrons to form ions. Thus, white dwarfs exceeding this limit will "explode."*

Interestingly, no white dwarfs have been found with a mass greater than the 1.4 mass limit. To date, most white dwarfs that have been discovered average about 0.6 the mass of our sun. It is speculated that the **supernova** observed and reported by Tycho Brahe in 1572 and another in 1604 by Johannes Kepler may each have been the collapse of a white dwarf star that pulled off mass from nearby red supergiants at a rate greater than could be eliminated by radiation from the white dwarf. This new mass was attracted internally by the gravitational pull of the white dwarf, causing an increase in its mass exceeding the 1.4 mass limit. Thus, a giant nuclear explosion occurred, creating a supernova.

Chandrasekhar also believed that as stars exhaust their nuclear fuel they begin to collapse by internal gravitational attraction, which ceases when a balance is established by the outward pressure of ionized gases. This gas is a high concentration of electrons, leaving behind ions, which become very dense. One thimbleful would weigh several tons on Earth due to the collapsed star's density.

It is estimated that most white dwarfs are "leftovers" of mass pulled from more massive stars. It is also speculated that in the long-distant future of the universe, all stars will become white dwarfs, and then we may have a static, or unchanging universe (thermodynamic equilibrium) because no other bodies would be available from which they could gather in extra mass and exceed the Chandrasekhar limit.

See also Brahe; Kepler

CHANG'S THEORIES AND CONCEPTS: Mathematics and Astronomy: *Cheng Chang* (c.78–142), China.

Chang's concept of pi: *Pi is the square root of 10, which equals 3.1622.*

This was one of the most original and most accurate methods of determining the value of pi up to this time, with the exception of Archimedes' geometric method of "perfect exhaustion." Many early mathematicians were intrigued by the relationship of the diameter of a circle to its circumference. This led to the idea of forming a series of geometric squares or polygons within the bounds and adjacent to the outer circumference of a circle and then calculating the known parameters of the squares or polygons (*see also* Archimedes).

Chang's concept of the universe: *The universe is not a hemisphere rising over Earth, but rather the universe consists of a large sphere with Earth at the center, similar to the yolk in the center of an egg.*

The early Greeks, including Aristotle, believed the universe consisted of a series of crystal hemispheres suspended above Earth. Chang's idea was the first to consider a spherical universe. Further, he developed an instrument to measure the major circles of the celestial bodies and demonstrated how they intersected at various points on Earth. He also developed an instrument that used flowing water to measure the movement of the stars (*see also* Aristotle).

Chang's concept of earthquakes: *Earthquakes are caused by dragons fighting in the center of the earth.*

From this idea Chang developed an instrument shaped in the likeness of several heads of dragons. A ball was held inside the mouth of each of the heads. When an earthquake occurred, a pendulum device would expel a ball from one of the mouths of one of the dragon heads, which would then determine the direction of the earthquake. Although Chang's "seismograph" was inaccurate, it was developed and used in the Far East for over seventeen hundred years before a more accurate one was designed in the West that used the Richter scale.

See also Richter

CHANG'S THEORY OF CAPACITATION: Biology: *Min Chueh Chang* (1909–1991), United States.

> *The male sperm must spend some time traveling in the reproductive organs of the female before it can fertilize the egg.*

Chang called this time factor, whereby sperm become more potent while in the female reproductive tract, the *capacitation factor.* He also believed that male seminal fluid has a "decapacitation" substance that prevents sperm from fertilizing the egg. Although no such factor or substance has yet been identified, it is assumed it is this decapacitation factor that prevents other sperm from uniting with an egg once one sperm has penetrated the ovum.

Using rabbits, Chang conducted much of the research with in vitro fertilization, where the ova (egg) is fertilized by a male sperm outside the body and then transplanted into the female rabbit's uterus. His research pioneered the way for others to perfect human in vitro fertilization.

Chang's work also provided much of the knowledge used to set up experiments by American biologist and researcher Gregory Pincus (1903–1967) to demonstrate that injections of progesterone into rabbits would prevent contraception. This was pioneering work for several modern methods of contraception.

CHAPMAN–ENSKOG KINETIC THEORY OF GASES: Mathematics/Physics: *Sydney Chapman* (1888–1970), England.

In the nineteenth century James Clerk Maxwell and Ludwig Boltzmann developed the general mathematical concept that describes the properties of gases as partially determined by the molecular motion of the gas particles, assuming the gas molecules follow classical mechanics. This is referred to as the *Maxwell–Boltzmann distribution* that gives gas particles a specific momentum.

In 1911 Chapman developed the next logical step in the theory of gas particles. He performed the mathematics necessary to prove the kinetic theory of gases.

The Chapman–Enskog theory provides a complete treatment and solution to the mathematics of the Maxwell–Boltzmann equation by using approximations to determine the average path of gas particles.

This joint theory is also known as the *Enskog theory* because the Swedish mathematical physicist David Enskog (1884–1947) also worked independently on this theory.

Chapman also used mathematics to predict the thermal diffusion of gases and the electron density at different levels of the upper atmosphere. In addition, he determined the detailed variations in Earth's magnetic field and related this to the length of the moon's day. (Because the moon keeps the same side pointed toward Earth, it rotates once every 27.3 days.) He demonstrated not only that the moon causes tidal effects on Earth's water and land, but there is a much weaker tidal effect on Earth's atmosphere. Chapman's work enabled other scientists to measure more accurately the kinetic motion of molecules as related to heat, and to understand better the ideal gas law, thermodynamics, and **geomagnetism**.

See also Boltzmann; Boyle; Gilbert; Ideal Gas Law; Maxwell

CHARGAFF'S HYPOTHESIS FOR THE COMPOSITION OF DNA: Biology: *Erwin Chargaff* (1905–2002), United States.

> *In the DNA molecule, the number of adenine (A) nucleotide units always equals the number of thymine (T) nucleotides, and the number of guanine (G) units always equals the number of cytosine (C) units.*

Chargaff's earlier work used paper chromatography and spectroscopy to study the composition of DNA in different species. He found that within one species, the DNA was always the same, but there was a difference in DNA composition between species. He believed there must be as many forms of DNA as there are species, even though much of the DNA was similar for all species. (It has been determined about 98+% of human and chimpanzee DNA is identical.) At this point, he realized that a pattern of consistency of AT nucleotide pairs and GC nucleotide pairs appeared in nucleic acid molecules. Although Chargaff did not follow up on this discovery, it enabled Crick and Watson to arrive at the placement of the AT and GC pairs inside the helix structure of the DNA molecule (*see* Figure C5 under Crick). Scientists are continuing to explore the many possible benefits of this discovery for the betterment of humankind.

See also Crick; Franklin (Rosalind); Watson

CHARLES' LAW: Chemistry: *Jacques Alexandre Cesar Charles* (1746–1823), France.

> *When the pressure remains constant, the volume of a gas is directly proportional to its temperature.* $V/T = \text{constant} = n/P$. *It might also be stated as: The volume of a*

fixed amount of gas that is at a constant pressure is inversely proportional to its temperature, VnP/T, where the nP represents the constant pressure on the fixed volume of gas.

Jacques Charles, originally an employee of a French government agency, became a physics professor at the Conservatoire des Arts et Métiers in Paris. He established the direct relationship between the temperature and the volume of gases. Aware of the flights of hot air balloons, Charles realized that as the air in the balloon became hotter, it expanded and thus became lighter due to a decrease in its density and an increase in its volume. As long as the fire at the bottom opening of the balloon heated the air, the air would expand and become lighter than the air outside of the balloon. When the air cooled, it decreased in volume and became heavier, causing the balloon to descend. He was also aware of the work of Henry Cavendish, a British chemist, who produced hydrogen gas that was much lighter than hot air and thus more buoyant. Even better, hydrogen did not lose as much of its buoyancy as did hot air as it cooled. On August 27, 1783, Jacques Charles, and his brother, Robert, made the first flight in a hydrogen-filled balloon. On a later flight, they reached an unprecedented altitude of just under 2 miles. This flight made him famous with the public and royalty. The danger of using hydrogen for lighter-than-air ships was recognized even in these early days, and its use for this type of airship was halted after the 1937 explosion of the *Hindenburg* zeppelin while mooring in New Jersey.

Charles' gas law led to further experimentation by Gay-Lussac, Dalton, and other scientists interested in the nature of matter and resulted in what is known as the "ideal gas law," a combination of several gas laws, including Boyle's Law.

See also Avogadro; Boyle; Dalton; Galileo; Gay-Lussac; Ideal Gas Law

CHARNEY'S THEORETICAL METEOROLOGY: Physics and Meteorology: *Jule Gregory Charney* (1917–1981), United States.

Charney proposed two important theories related to meteorology:

1. *Weather can be understood by the use of computer models and mathematics.*
2. *Biogeographical feedback mechanisms are responsible for desertification of landmasses.*

Jule Charney received his PhD from the University of California at Los Angeles in 1946. He then became a member of the Advance Studies Group at Princeton, New Jersey, and in 1956 became head of meteorology at Massachusetts Institute of Technology (MIT) until his retirement in 1977.

While they were at the Institute of Advanced Studies in the 1940s Charney, along with John Von Neumann, developed a large computer that required an extensive air-conditioned room in which it needed to be housed due to the tremendous heat its many vacuum tubes generated. They decided that it would be a logical use of the new Electronic Numerical Integrator And Calculator (ENIAC) computer, which was built during the period 1942 to 1945, to set up calculations that could predict weather for short periods of time. In 1949 they succeeded in more accurately predicting the weather for a four-day period. This exceeded the reliability of any other method of predicting weather over short periods of time. Today, computers can reasonably and accurately predict local and regional weather for about one week. The record of using computers, even supercomputers, to predict long-term climate changes is not nearly as successful. One reason: even the best computer/climate models cannot accurately predict long-term (or even short-term) climate changes on a regional or worldwide basis due to the many interacting variables that affect long-term cyclic climate factors, such as sunspots, temperature/pressure fluctuations of the sun, ocean, and atmospheric anomalies, and Earth's slight pertubations (wobble on its axis), among other factors. Short-term computer/mathematical weather predictions are possible, but they are not always accurate partly because weather (as well as long-term climate) does not behave as the computer models predict.

While at MIT, Charney proposed his theory of desertification in his 1974 *Theory of Biogeographical Feedback*. This concept considers the biological, geological, and geographical factors for a particular region. Because severe droughts have persisted on the African continent, particularly in the central and northern regions, Charney's theory considered the following: overgrazing and the cutting down of forest timber for firewood led to an increase in **albedo** of the land (the reflection of sunlight from the land into the atmosphere). This results in a cooler land surface and a warmer lower atmosphere, resulting in less cloud formation and therefore less rain. His theory that the less plant cover of land surfaces the greater the albedo is not completely accepted, particularly as the only or main causation of desertification.

CHARPAK'S CONCEPT OF TRACKING PARTICLES: Physics: *Georges Charpak* (1924–), France. Georges Charpak, the Polish-born French physicist was awarded the 1992 Nobel Prize for Physics for his work in inventing a device known as the "drift chamber" for detecting subatomic particles that provided a means of analyzing these particles by using computers.

> *Because only one particle in a billion interacts when exploring the deep parts of matter, the single event is not easily discernable, and photographic techniques are inadequate to the task. Therefore, a high-speed electronic device might be used to detect a greater number of events.*

The "cloud chamber," for which C.T.R. Wilson received the 1927 Nobel Prize for Physics, preceded the development of the "drift chamber" for detecting and analyzing subatomic particles. As charged particles passed through the cloud, they formed a "track" through the cloud in the closed chamber. Using the cloud chamber, Carl D. Anderson discovered the first antiparticle, known as the positron (a positively charged electron). He received the 1936 Nobel Prize for Physics for this endeavor.

Over the years other means of detecting subatomic particles and cosmic radiation used special photographic emulsions. The classic "bubble chamber" was the next device capable of detecting the movement and interactions of charged subatomic particles. Donald A. Glaser invented the bubble chamber in 1952 for which he received the Nobel Prize for Physics in 1960. This chamber was filled with overheated fluid; and as the charged particles passed through the liquid, they caused bubbles to form as the liquid boiled along the particle's tracks. These tracks could only be photographed at the rate of one per second. There were several problems with all of these instruments. One was that they only recorded a few particle "events" per second. Another was that they did not provide complete information about the particle. And another was that they do not lend the results to computer analysis.

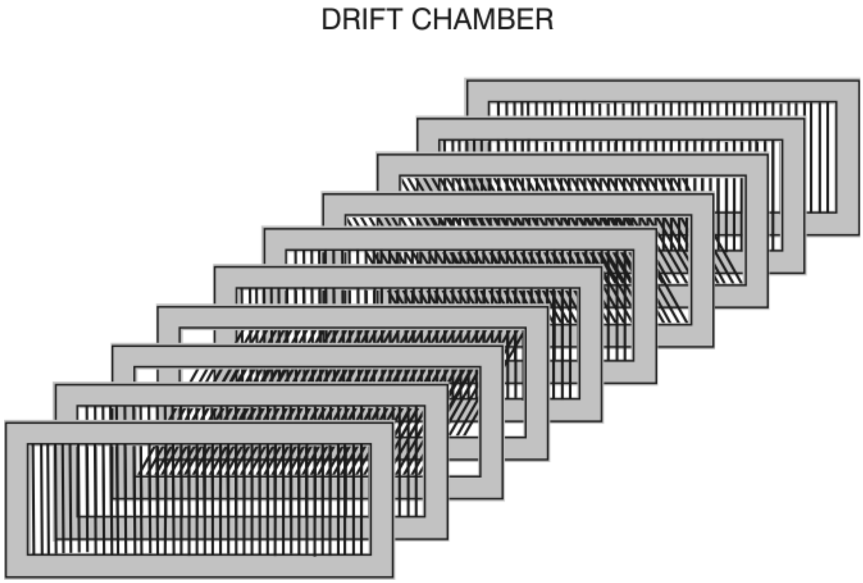


Figure C2. This multi-wire device can detect one million subparticle impulses a second that can then be analyzed by computers.

A number of new devices have been developed that actually track the subatomic particles' paths across a computer screen in three dimensions. These include the multiwire chamber that can track one million subatomic particles per second for computer analysis. Another was the wire spark chamber. During the 1970s Georges Charpak was doing his research at Conseil Européen pour la Recherche Nucléaire (CERN; also known as the European Organization for Nuclear Research) when he invented the improved "drift chamber" that helped revolutionize high-energy and subatomic particle physics. Conseil Européen pour la Recherche Nucléaire is located near Geneva, Switzerland. It is the world's largest subatomic particle physics laboratory with the world's largest particle accelerator.

As evidence of the importance of the invention of these detection devices is the number of Nobel Prizes for Physics that have been awarded to physicists and the discoveries made possible by their use. They have made great advances in related fields. For example, two important discoveries are 1) the J/psi particle in 1974 by Samuel Ting and Burton Richter, and 2) the W and Z subatomic particles by Carlo Rubbia and Simon Van der Meer. Not only does the drift chamber have application in physics, but it also contributed to research in the fields of biology and medicine as well as other industries.

See also C. Anderson; Glaser; Rubbia; Ting; Van der Meer; C. T. R. Wilson

CHARPENTIER'S GLACIER THEORY: Geology: *Jean de Charpentier* (1786–1885), Switzerland.

> *Glaciation is the agent responsible for the movement of boulders of one composition to an area where the boulders and rocks of a different composition are found.*

Early geologists were puzzled for many years by the presence of large boulders that did not seem to belong in the areas in which they were found. Some thought that they were carried to their new locations by icebergs, but there was no evidence that icebergs ever existed in these areas. Charles Lyell contended these boulders were brought to their locations by enormous floods; however, there existed no other evidence of any such giant water flow that would have been needed to move these huge rocks. Others claimed that the boulders were really meteorites from outer space. But no firm evidence supported this notion.

Charpentier's **glaciation** theory was correct but not well accepted by most scientists, except Louis Agassiz, who believed the idea viable and published his glacier theory "Studies on Glaciers" in 1840 before Charpentier published his paper titled "Essays on Glaciers" in 1841.

See also Agassiz; Lyell

CHEVREUL'S THEORY OF FATTY ACIDS: Chemistry: *Michel Eugene Chevreul* (1786–1889), France.

> *When treated with acids or alkali, animal fats break down to produce glycerol and fatty acids.*

Chevreul experimented with saponification, the process of producing soaps by treating animal fats with alkalis. By using alcohols to crystallize the product, he identified several fatty acids, including oleic acid, stearic acid, butyric acid, capric acid, and valeric acid, which are used in organic chemistry. He published his first paper titled "Chemical Researches on Animal Fats" in 1823. Chevreul and Joseph-Louis Gay-Lussac patented the process to make candles from the stearic fatty acid. Until this time tallow candles rendered from animal fat were used. They had an unpleasant odor, burned poorly, and were messy. The new fatty acid candles were harder, burned brighter, and were less odiferous. They were a better product and made a fortune for Chevreul and Gay-Lussac. Chevreul also experimented with and produced other fats including lanolin, cholesterol, and spermaceti (a waxy substance obtained from the head of the sperm whale). Later in life he worked with dyes and produced coloring from logwood, yellow oak, and indigo. He became professor of chemistry, and later director at the Musée d'Histoire Naturelle (Museum of Natural History) in France in the 1880s. He had a long and productive life of 103 years.

See also Gay-Lussac

CHU'S HYPOTHESIS FOR "HIGH TEMPERATURE" SUPERCONDUCTIVITY: Physics: *Paul Ching-wu Chu* (1941–), United States.

> *The combination of the proper amounts of yttrium, barium, and copper can be used under pressure to reach a critical temperature above that of liquid nitrogen.*

The Swiss physicist Karl Alexander Müller (1927–) developed material that achieved **superconductivity**, at an unprecedented high temperature (35K or −238°C). This temperature is very low compared to ordinary temperatures, and liquid helium is required to maintain a system at this temperature. Using Müller's results, Chu's goal was to make superconductivity practical. To achieve this, it was necessary to make a material that would be superconductive at a temperature at which a material could be cooled by liquid nitrogen. Liquid helium has a lower boiling temperature than liquid nitrogen but is too expensive to use on a regular basis. Nitrogen becomes a liquid at about 77 kelvin (K) (−195.5°C). Chu tried several combinations of metals as superconductors and finally developed a mixture that was stable. It was a ceramic-type substance consisting of the elements lanthanum, copper oxide, and barium that would become superconductive of electricity at a temperature of about 93 K. He experimented with various ratios of these three elements and then substituted yttrium for the lanthanum. In 1987 he used a mixture of $Y_{1.2}Ba0_{.8}CuO_4$ and was successful in achieving superconductivity at about 93 K. Because there is very little or no resistance to the flow of electricity through superconductors at these low temperatures, the potential for research possibilities is limitless. Superconductivity at even higher temperatures may lead to superefficient magnets, improved electromagnetic devices, such as computed axial tomography (CAT or CT) scanning equipment and magnetic resonance imaging (MRI), as well as other electrical equipment. Practical superconductivity will lead to the development of super-fast trains and less expensive transmission of electricity.

See also Nernst; Simon

CLARKE'S SUPERGENE THEORY: Biology: *Sir Cyril Astley Clarke* (1907–2000), England.

> *Supergenes are groups of closely linked genes that act as an individual unit and carry a single controlling characteristic.*

Clarke was interested in the phenomenon of butterflies' inheriting particular wing patterns referred to as *mimicry*—that is, one species (mostly insect species) exhibits a color, body structure, or behavior of another species that acts as camouflage. For example, the "eye" spots on the wings of butterflies that mimic another species protect the butterfly from predators. He found that male swallowtail butterflies carry supergenes as recessive. However, the characteristics are expressed as patterns for the females. It is now known that many inherited human traits and characteristics are controlled by supergenes. Clarke recognized a similarity between the supergenes that resulted in butterfly wing patterns and the blood antigen of rhesus monkeys, referred to as the Rh-factor. An Rh-negative mother and Rh-positive father may produce an Rh-positive child, which can lead to the development of Rh-antibodies in the mother if the child's blood leaks through the placenta. This can cause the destruction of red blood cells in future Rh-positive children born to the mother. Clark's wife suggested that he inject the Rh-negative mothers with Rh-antibodies because this was what destroyed the red blood cells of the fetus. This proposed solution to the problem proved ingenious because after injecting antibodies into the mother's blood the incompatible Rh-positive factor of the mother would be destroyed before the mother's own blood made antibodies, thus preventing her blood from destroying the red blood cells of her unborn baby. Clark tested prospective mothers and injected those with the Rh-negative blood factor with Rh-antibodies, thus counteracting the effects on future Rh-positive children. This testing and these procedures are now used by most obstetricians and hospitals and have saved many lives of newborn children.

CLAUDE'S CONCEPT FOR PRODUCING LIQUID AIR: Chemistry: *Georges Claude* (1870–1960), France.

> *When air is compressed and the heat generated by the increase in molecular activity is removed, a point will be reached at which the major gases of air will liquefy.*

Claude was successful in applying this principle on an industrial scale, forming the worldwide Air Liquid Company. The gases that make up air can be fractionally separated by this process, producing oxygen, nitrogen, carbon dioxide, argon, neon, and other noble gases. Because each of these gases becomes liquid at a specific temperature, the reverse also occurs. As the temperature of liquid air containing all of these gases in liquid form increases, each specific gas "boils" off at its specific evaporation temperature, where it can be isolated and collected as a pure gas. Claude was the inventor of neon lighting (glass tubes containing neon gas at less than normal pressure). When an electric discharge is sent through the gas, it glows with the familiar red light.

CLAUSIUS' LAWS AND THEORY OF THERMODYNAMICS: Physics: *Rudolf Julius Emmanuel Clausius* (1822–1888), Germany.

Clausius' law: *Heat does not flow spontaneously from a colder body to a hotter body.* In an early form, the law was stated as: *It is impossible by a cyclic process to transfer heat from a colder to a warmer reservoir without changes in other close-by bodies.*

The conservation of energy is a fundamental law of physics and is often called the first law of thermodynamics, which states that the total energy of a closed system is conserved. Clausius' law is an early statement of the second law of thermodynamics, and it led to the concept of entropy.

Clausius' theory of entropy: *In an isolated system, the increase in entropy exceeds the ratio of heat input to its absolute temperature for any irreversible process.*

The three classifications assigned to thermodynamics processes are *natural, unnatural*, and *reversible*. The *natural* process proceeds only in a direction of equilibrium. It is a reversible process only if additional energy (heat) enters the isolated system. A hot body transfers some of its heat (hotness) to a cold body until both are at the same temperature as their surroundings—thus equilibrium. The *unnatural* process never occurs over extended time because the unnatural process would require moving away from equilibrium (reverse the arrow of time). And *reversible* systems are idealized in the sense they are always arriving at different states or stages of equilibrium (e.g., growing living organisms) until their death. In a perfect closed system, Clausius' ratio (entropy) would always remain constant. However in real life, every process occurring in nature is irreversible and directional (the arrow of time is pointed in only one direction) toward disorder. Thus, there is always an increase in entropy, which sooner or later leads to complete disorder and randomness and a static (unchanging) universe (i.e., equilibrium).

More recently, concepts of entropy have been expanded to the analysis of information theory.

Consequence of Clausius' second law of thermodynamics: *The amount of energy in the universe is constant while the entropy of the universe is always increasing toward a maximum. At some future point, this maximum disorder will result in the unavailability of useful energy.*

The second law of thermodynamics is also known as "time's arrow" because it only progresses in one direction—toward disorganization. For any irreversible process, entropy will be increased. In other words, a greater state of disorganization or randomness will exist until equilibrium is reached. The only way entropy or an entire system can be decreased is by extracting energy from the system. The entropy of a part of the system may decrease if the entropy of the rest of the system increases enough. For example, the sun continually supplies energy to Earth. Otherwise, total entropy (disorder) would soon occur on Earth. This also applies to small temporary systems, such as some chemical reactions, crystallization, and growth of living organisms. The sun provides most of the energy used on Earth (with the exception of radioactive minerals). Energy is pumped into all living systems through plants as food, resulting in highly ordered complex molecules and growth in living organisms. Thus, the entropy of some parts of the universe (but not the entire universe) is decreased as organisms grow and become more organized through the input of energy. However, the entropy of the universe is increased by the radiation of the sun and other stars. Upon death, the second law of thermodynamics proceeds, resulting in the disorganization of the organism and its complex molecules. Without Earth receiving the sun's energy, entropy will increase and become all-encompassing, leading to the death of all living organisms.

Clausius summarized the first and second laws of thermodynamics as follows: "The energy of the universe is constant, and the entropy of the universe will always tend toward a maximum."

See also Boltzmann; Carnot; Fourier; Heisenberg; Kelvin; Maxwell; Rumford; Simon

COCKCROFT–WALTON ARTIFICIAL NUCLEAR REACTION: Physics: *Sir John Douglas Cockcroft* (1897–1967) and *Ernest Thomas Sinton Walton* (1903–1995), England. They were joint recipients of the 1951 Nobel Prize for Physics.

> *The transmutation reaction progressed as follows: $_3$Li-7 + $_1$H-1 → $_2$He-4 + $_2$He-4 + 17.2 MeV: where $_3$Li-7 is a heavy isotope of lithium, $_1$H-1 is a proton (hydrogen nucleus), $_2$He-4 are alpha particles (helium nuclei), and 17.2 MeV is in millions of electron volts of energy.*

This first artificial nuclear reaction was the lithium reaction that occurred in 1932 and was made possible by Cockcroft's development of a proton accelerator and E.T.S. Walton's invention of a voltage multiplier that increased the speed of the proton "bullets." This was the beginning of the nuclear era. The lithium nuclei (the target) were bombarded by high-energy hydrogen nuclei (protons), resulting in the production of two

> Before joining the British Army in 1915 Cockcroft studied mathematics at Manchester University in England. After the war he studied electrical engineering and later attended Cambridge University where he graduated with a degree in mathematics. Following graduation he joined Rutherford's group at the Cavendish Laboratory. This is where he met E.T.S. Walton who had constructed a device that multiplied voltages that could be used to accelerate positive protons. They were the first to successfully produce an artificial nuclear reaction by bombarding lithium nuclei with protons. In 1940 Cockcroft traveled to the United States to join the Tizard Mission that was charged with the exchange of science and technology between Canada, England, and the United States (It was named after Henry Tizard [1885–1959] the head of Britain's Aeronautical Research Committee who headed the mission.) He also assisted in developing radar. In 1946 he returned to Great Britain to head up the new British Atomic Energy Research Establishment at Harwell, England. In 1948 he was knighted as Sir John Douglas Cockcroft. Later in 1959 he was appointed master of Churchill College in Cambridge that emphasized science and technology. Cockcroft combined his research and administration skills, as he became a leading statesman of science.

alpha particles (helium nuclei), plus a small amount of energy. There were no cyclotrons or particle accelerators available so they used particles (protons) from a natural radioactive source. This provided the information and knowledge needed to continue the development of powerful cyclotrons and particle accelerators that produced nuclear fission (transmutation) reactions, giving rise to the use of nuclear energy for the production of electricity, radioisotopes, and the atomic (fission) bomb.

See also Chadwick; Fermi; Hahn; Meitner; Szilard; Walton

COHN'S BACTERIA AND CELL THEORIES: Biology: *Ferdinand Cohn* (1828–1898), Germany.

Cohn's infectious disease theory: *Microscopic bacteria are simple organisms that can cause diseases in other plants as well as animals.*

Cohn's study of microscopic organisms led him to develop the first classification of bacteria titled "Researches on Bacteria" that he published in his journal in 1872. His classification system is basically still used today. He experimented with boiled solutions of bacteria and suggested that some bacteria can develop resistance to external environmental influences, including heat-resistant spores that led to his research on the formation of heat-resistant spores formed by *Bacilus subtilis*. Later, similar bacteria and other forms of life were found living around the steam vents on the bottom of the oceans where the temperatures were much too high to support normal surface life. Based on his research, and unlike many biologists of his day, Cohn did not believe in spontaneous generation, a theory that life can start in rotting garbage (*see also* Redi).

Cohn's theory of protoplasm: *The protoplasm found in plant and animal cells is essentially of the same composition.*

Protoplasm is the colloidal substance composed of mostly complex protein molecules found in all living cells. In green plants the protoplasm contains chlorophyll, which in the presence of sunlight manufactures complex organic compounds (mostly carbohydrates from carbon dioxide and the hydrogen from water), while liberating oxygen mainly from the water as a waste product. All animal and plant cells require the food produced by this process, called *photosynthesis*.

Cohn was a popular lecturer who presented biology in an interesting manner to a large and appreciative audience. He not only published his own research and lectures but also supervised the publication of Robert Koch's research on the life cycle of the anthrax bacillus. Others biologists including Louis Pasteur used Cohn's research and publications.

See also Koch; Pasteur; Redi

COMPTON'S WAVE–PARTICLE HYPOTHESES: Physics: *Arthur Holly Compton* (1892–1962), United States. Arthur Compton and Charles T.R. Wilson jointly received the 1927 Nobel Prize for Physics.

> Compton effect: *When X-rays bombard elements, such as carbon, the resulting radiation is scattered (reflected) with a wavelength that increases with the angle of scattering.*

For this effect to occur, the X-rays must behave as particles (photons) that during the collision transfer their energy to the electrons of the carbon. This reaction indicates that X-rays behave as particles as well as waves. Compton used Charles Wilson's "cloud chamber" to assist in detecting, tracking, and identifying these particles. The

Compton effect was the first experimental evidence of the dual nature of electromagnetic radiation, such as radio waves, light, ultraviolet radiation, microwaves, X-rays, and gamma rays that exhibit characteristics of waves and particles.

Compton's hypothesis for cosmic rays as particles: *If cosmic rays have characteristics similar to charged particles, then there should be a variation in their distribution by latitude caused by Earth's magnetic field.*

If such an effect by the magnetic field could be detected, then it could be concluded that cosmic radiation consists of charged particles and is not pure electromagnetic radiation. This hypothesis was later proved correct in 1938 by measuring the distribution of cosmic rays from outer space as they were affected by Earth's magnetism, which proved that their concentrations were different at different latitudes of Earth's surface.

See also C. Anderson; Hess; Rutherford; C. T. R. Wilson

CONWAY'S GAME OF LIFE THEORY: Mathematics: John Horton Conway (1937–), England/United States.

Conway's "game of life" is: *An infinite grid of cells, either alive or dead, that interact with eight surrounding neighbor cells that are located either above, below, or diagonally from adjacent cells. As time progresses, each of the following rules occur:*

1. *A live cell with fewer than two neighbors dies.*
2. *Any cell that is surrounded by three or more neighboring cells dies.*
3. *Any cell with two or three neighbors lives for the next generation.*
4. *Any dead cell with just three neighbors will come to life.*

The first pattern is just for the first generation of the system. For the second pattern, the rules apply to all (every) cells in the first generation as births and deaths occur at the same time. Repeat the rules to continue for future generations.

This game of life is the result of Conway's interest in John von Neumann's hypothetical machine that could replicate itself. In 1940 von Neumann found a mathematical model for such a machine with rules following a Cartesian grid. Conway simplified von Neumann's ideas for a self-replicating machine and devised the "game theory of life." His "game" was published in Martin Gardner's

John Conway was born in Liverpool, England, the day after Christmas in 1937. Although his family was not poor, they experienced difficult times during World War II in England. Interested in mathematics from the age of four, he was first in his class in mathematics in his elementary school and excelled in the subject in high school. He also developed an interest in astronomy that he still follows. He entered Gonville and Caius College at Cambridge where he was awarded a BA in mathematics in 1959. While at Cambridge, he began his research in number theory and games, as he liked to play games in the college's game room. He was awarded his PhD in mathematics in 1964 and was assigned as lecturer in pure mathematics at Cambridge. Following this period his interests covered many areas in the field of mathematics that led to his famous cellular automata theory (game of life), group theory, surreal numbers, knot theory, quadratic forms, coding theory, fractals, and tilings. John Conway became a fellow of the Royal Society of London in 1983. He received many awards including the Berwick Prize and the Poly Prize from the London Mathematical Society, the Esser Nemmers Prize in Mathematics from Northwestern University, the Leroy P. Steele Prize for Mathematics by the American Mathematical Society, the Joseph Priestley Award from Dickinson College located at Carlisle, Pennsylvania in 2000, and was given an Honorary Doctorate in Science by the University of Liverpool in the year 2001. In addition he has written several books on his original theories. He has taught at Princeton University in New Jersey since 1986.

column "Mathematical Games" in the October 1970 issue of *Scientific American* magazine. The game became very popular with professional and amateur mathematicians and also made Conway popular.

Conway also invented a new system of numbers and a theory of knots that identifies the differences in 801 different types of knots based on the number of "crossings" in the knot if the crossings are no higher than 11. He helped develop the field of "group theory" where groups, similar to prime numbers, cannot be broken down into smaller groups. Conway contributed to the identification of several types of groups leading to a total of twenty-six groups described in the fifteen thousand pages of the publication explaining the "enormous theorem."

COPERNICUS' COSMOLOGY THEORIES: Astronomy: *Nicolaus Copernicus* (1473–1543), Poland.

Copernicus' heliocentric theory of the universe: *All the spheres (planets and moons) revolve about the sun as their midpoint; therefore, the sun is the center of the universe.*

At the time of Copernicus' pronouncement, the concept of a sun-centered universe was not really new. Aristarchus of Samos (c.320–250 BCE) reportedly stated that the sun and stars were motionless and the planets, including Earth, revolved in perfect circles around the sun. However, no attention was paid to his theory for almost two thousand years because the Earth-centered universe, as postulated by Aristotle and Ptolemy, was the accepted truth—that is, until the Copernican **heliocentric** model was proposed. Copernicus was influenced by the Pythagorean Philolaus (c.480–400 BCE) who theorized that the planets, including Earth, moved around a central fire. Philolaus believed that we could not see this fire because we lived on the side of Earth that was always turned away from it. Copernicus' model engendered much controversy among the clergy, as well as most scientists, until others were able to study and understand his new model, which also explained planetary motion (see Figure C3).

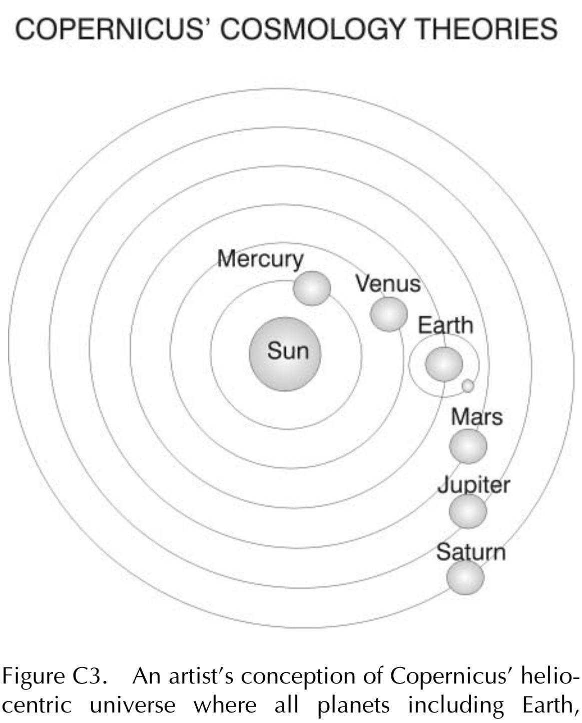


Figure C3. An artist's conception of Copernicus' heliocentric universe where all planets including Earth, revolve around the sun. His rationale was that if the sun is the midpoint of the planets' orbits, then the sun must be at the center.

Copernicus' theory of planetary positions: *Superior planets are those whose orbits are larger than Earth's and therefore, are farther from the sun than is Earth. Inferior planets are those whose orbits are smaller than Earth's and are closer to the sun.*

As a result of this theory, several other concepts to explain planetary motion were proposed. When an inferior planet is between Earth and the sun, it is in line of sight with the sun and is said to be in "inferior conjunction." When the planet passes on the far side of the Sun, away from Earth, the planet is in opposition and is said to be in "superior conjunction." Further observations of planetary motion led Copernicus to distinguish between the planet's ***sidereal period***—its actual period of revolution around the sun—and the *synodic period*—the time period of two successive conjunctions of a planet as seen from Earth. Therefore, the synodic period is what is directly viewed from Earth, as it is the time required for the planet to progress from one 180-degree opposition to the opposition of the next cycle, as related to Earth.

Copernicus was also aware his model required the inferior planets to move faster in their smaller orbits, while the speed of the superior planets was slower as they revolved around the sun. This information later became important for Kepler in the development of his laws of planetary motion.

Copernicus' theory of planetary distance from the sun: *Because the planets travel in perfect circles, they can be viewed as a direct line of sight to the sun, as well as at a 90-degree right angle, which forms a right triangle with the sun. The distance from the sun to the planets can be determined by geometry and trigonometry.*

At this time in history it was believed that all celestial motion, including planetary motion, progressed in perfect circles. Also, there were only six known planets in Copernicus' day. Copernicus' calculations for the distance of planets to the sun were excellent, considering that he believed their orbits to be perfect circles. His figures are close to what we now know about elliptical orbits of planets and their distances from the sun. Current figures are based on Earth's distance to the Sun as being 1 unit. This distance is the standard astronomical unit (AU), which equals the mean distance of 92,956,000 miles from Earth to the Sun. AUs are used to calculate the distances for the other planets to the sun.

Planet	Copernicus' Data (AUs)	Modern Distance (AUs)
Mercury	0.38	0.39
Venus	0.72	0.72
Earth	1.00	1.00
Mars	1.52	1.52
Jupiter	5.22	5.21
Saturn	9.18	9.55

Copernicus' theory of planetary brightness: *All the planets travel in circles around the sun; thus they are at different distances from Earth. Therefore, as their distances from Earth differ, so does their brightness.*

These theories raised another question: If Earth actually revolved around the sun, why didn't the position of the stars change every six months of Earth's yearly orbit of the Sun? This question is based on **parallax**—the apparent change in position of an object when viewed from two different positions.

Copernicus' conclusion about the size of the universe: *Stars seem not to move and therefore must be located at tremendous distances in space. Thus, the universe is much larger than formerly believed.*

Copernicus based this theory on the concept of parallax, which is dependent on the distance between two geographic sites at which the stars are viewed and the distance separating the observer and the actual object. In other words, even when viewed from opposite positions every six months in Earth's orbit, the stars are so distant they seem to stay in one position. About two hundred years later, with the development of improved instruments, a slight parallax of the stars was measured. But for the ordinary viewer on Earth, this slight parallax displacement is not noticeable. Copernicus was one of the first to conceptualize a vast universe that for the next hundred years remained incomprehensible.

Copernicus' theory of epicycle motion of the planets: *The minor irregularities in the motion of planets revolving around the sun can be explained by the epicycle each planet traces as it progresses in its own orbit.*

Ptolemy's Earth-centered model of the universe required the extensive use of epicycles to explain planetary motion. Because Copernicus maintained that planets revolved around the sun in perfect circles, he too required the use of epicycles to explain the irregularities in their motion. Several centuries later, it was determined that not all of celestial motion is in circles, and planets, moons, and comets traveled in ellipses of one type or another. An epicycle may be thought of as the planet moving in its own series of small circles as it progresses around the circumference of its orbit.

Copernicus' theory of the Earth spinning on its axis: *The motions of Earth consist of two or more component motions. One motion is revolving; the other is rotating.*

Most philosophers and scientists in Copernicus' day rejected the concept of Earth's revolving around the sun. The second contention—that Earth spins on its axis as it revolves around the sun—was even more difficult to comprehend. Most people claimed that their common sense dictated it was not possible and offered these arguments against a rotating Earth: 1) If Earth spun on an axis, why didn't objects fly off into space? 2) It would be impossible for anything moveable to be firmly affixed to Earth. 3) Birds would have to fly faster in the direction of Earth's rotation just to stay in the same place. 4) If a person jumped up, he would come down in a different spot because Earth would have moved.

Copernicus not only lived during the Renaissance, he was a Renaissance man with interests in economics, law, medicine, mathematics, as well as astronomy. During this period the Roman Catholic Church needed better astronomical information to set correct times and dates for special holidays and ceremonies. They approached Nicholas Copernicus, a monk in the church, for assistance. His studies on their behalf led to his astronomical theories that were not always accepted by the Church. His model of the solar system did not become generally known until 1515 as he shared his ideas only with friends. His studies were published in *De Revolutionibus Orbium Celestium* in the same year he died (1543).

See also Brahe; Coriolis; Galileo; Kepler; Ptolemy

COREY'S THEORY OF RETROSYNTHETIC ANALYSIS: Chemistry: *Elias James Corey* (1928–), United States. Elias Corey was awarded the 1990 Nobel Prize in Chemistry.

> *Retrosynthetic analysis occurs when the whole target chemical compound (the compound to be studied) is divided into subunits for analysis and then synthetically recombined.*

This was a new approach to analyzing chemical substances, particularly complex organic molecules. Corey and his research teams reduced complex molecules to smaller and smaller "pieces" and then recombined these units to arrive at the original or an altered molecule. In this manner, they determined how to synthesize many organic compounds for medical use. An example is the synthesis of prostaglandin hormones useful in treating infertility and inducing labor. Using his retrosynthetic concept, Corey developed a new computer program that greatly assisted chemists in their analysis and synthesis of organic compounds.

Elias Corey received his undergraduate degree at the Massachusetts Institute of Technology in 1948 and his graduate degree in 1950, both in chemistry. He became interested in chemistry after auditing a course in organic chemistry. After receiving his doctorate, he was employed by the University of Illinois in Champaign-Urbana, and nine years later moved to Harvard as a professor of chemistry. He is best known for new and unique methods for synthesizing organic molecules, particularly his "retrosynthetic analysis" technique that examines parts of whole molecules. He published his methods in *The Logic of Chemical Synthesis* in 1989.

CORIOLIS' THEORY OF FORCES ACTING ON ROTATING SURFACES: Physics: *Gustave-Gaspard Coriolis* (1792–1843), France.

> *An inertial force acts on rotating surfaces at right angles to the rotating Earth, causing a body to follow a curved path opposite the direction of the rotating Earth.*

The Coriolis effect is greatest if an object is moving longitudinally on Earth—from either pole to the Equator along longitudinal lines. In the Northern Hemisphere the apparent motion, when viewed from the North Pole, is to the right; for the Southern Hemisphere, when viewed from the South Pole, it is to the left. It affects the oceans and atmosphere on Earth but is a much weaker force than gravity. Even so, over great distances it causes cyclones, which are low-pressure areas that can develop into hurricanes, and water whirlpools to circle counterclockwise in the Northern Hemisphere. Conversely, anticyclones may develop into typhoons, which rotate clockwise in the Southern Hemisphere. The Coriolis effect influences ocean currents, including El-Niño, as well as other local and worldwide weather and climate phenomena.

The magnitude of the Coriolis effect is the velocity of the object compared to Earth's angular velocity for the given latitude and is the reason rockets and spacecrafts are launched to the east. The Coriolis effect gives rockets an extra boost as Earth spins eastward. Also, missile-launching sites are usually located on coastal areas so that any defective rockets or missiles will fall on water rather than land. Although other scientists recognized the effect caused by Earth's rotation as an inertial force, it was Coriolis who worked out the mathematics for this force and was the first to publish his results. The mathematical parameter for the Coriolis force is twice the component of Earth's angular velocity around the local vertical as expressed in: $2\Omega \sin \Phi$, where Ω is the angular momentum of Earth and Φ is the latitude on Earth's surface. This complex force resulting from the rotation of Earth on its axis was not apparent in the days of Copernicus and Galileo because it is a force much too weak to have been recognized or measured in their times.

Although the Coriolis force *deflects* or moves air and water masses to the right in the Northern Hemisphere, the *rotation* of the large air masses (hurricanes) is to the left (*see* Figure C4).

There are several misconceptions about the Coriolis effect. One is that it will affect the direction of rotation of flow of relatively small volumes of water, such as the

The Coriolis effect on Earth may be summarized as follows

1. The Coriolis effect is an inertial force caused by Earth's rotation to the east. Its strength is altered with the degree of speed of Earth's air and water masses.
2. The Coriolis effect *increases* as one goes from the equator toward the polar regions. The polar regions are at *right angles* to the axis of Earth's rotation.
3. The Coriolis effect *decreases* as one nears the equator. At the equator Earth's surface is *parallel* to the axis of rotation.
4. The Coriolis effect causes air and water masses to be *deflected* and turn *right* in the Northern Hemisphere and to be *deflected* and turn *left* in the Southern Hemisphere. Note: the direction of *deflection* is not to be confused with the direction of *rotation* of the air and water masses.
5. The geotropic flow is a gradient flow where the Coriolis force balances the pressure of the horizontal force of the wind.

draining of water down a bathtub or sink drain or when flushing a toilet. The direction of rotation of water down a drain can be made to go in either direction by swirling the water around before the plug is pulled. The Coriolis effect is much too small to be effective at this level of magnitude. In addition, the shape of the tub, the nature of its surface, the water's disturbance as it enters the tub, sink, or toilet, and how the drain is opened have more effect on the direction of the whirlpool of draining water than the Coriolis effect. This becomes more understandable when considering that Earth spins on its axis every 24 hours and affects very large masses of air and the oceans, whereas the tiny amount of water going down the drain might be said to be "just a drop in the larger bucket."

When firing a rifle, the bullet is affected by gravity and follows a curved path, but the distance the bullet travels is too small to be affected by the Coriolis effect. However, when firing very long-range artillery shells, the calculation of the ballistics of the projectiles' flight must take into consideration the Coriolis effect. In World War I the Germans developed a huge gun that bombarded Paris from a distance of 120 kilometers. This distance required the Coriolis effect to be taken into consideration when aiming the gun.

Cyclones are low-pressure areas in the Northern Hemisphere that, when under the right conditions, form hurricanes. They generally travel in a northerly direction, and the further north, the stronger the Coriolis effect. Hurricanes seldom move toward the equator because the closer you get to the equator, the less effect of the Coriolis force. In fact, the Coriolis effect is zero at the equator.

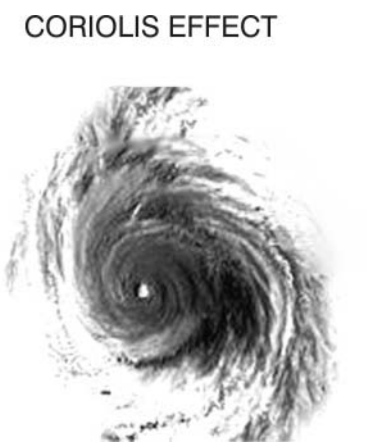


Figure C4. The Coriolis Effect causes winds and hurricanes to rotate counterclockwise in the northern hemisphere, and clockwise in the southern hemisphere.

THE CORI THEORY OF CATALYTIC CONVERSION OF GLYCOGEN: Chemistry: *Carl Ferdinand Cori* (1896–1984) and *Gerty Theresa Radnitz Cori* (1896–1957), both from the United States, jointly received one-half of the 1947 Nobel Prize for Physiology or Medicine. The other half of the 1947 prize was awarded to Bernardo Houssay (1887–1971) for his work with the pituitary gland and sugar metabolism. The only other husband-and-wife teams of scientists to share a Nobel Prize besides the Coris were Marie and Pierre Curie in 1903 and the Joliot-Curies in 1935.

Coris' hypothesis for glucose conversion: *The complex carbohydrate glycogen stored in the liver and muscles is converted, as needed, to energy, in the form of glucose-6-phosphate by the enzyme phosphoglucomutase. The process is reversible.*

Carl and Gerty Cori collaborated on biochemical research projects dealing with the analysis of enzymes and glycogen (sugars and starch). They isolated a chemical from dissected frog muscle identified as glucose-1-phosphate, where a molecular ring containing six carbon atoms joined this complex molecule. This new compound was named the Cori-ester and was shown to convert to the more complex sugar form after it was injected into animal muscles. Their research led to a more complete understanding of the role of high blood sugars, diabetes, insulin, hormones, and the pituitary gland. Their research also opened the door for a more complete understanding of the important role phosphates play in producing the energy in animal cells.

COULOMB'S LAWS: Physics: *Charles Augustin de Coulomb* (1736–1806), France.

> Coulomb's fundamental law of electricity: *Two bodies charged with the same sort of electricity will repel each other in the inverse ratio of the square of the distance between the centers of the two bodies.*

Coulomb devised this law after developing an extremely sensitive torsion balance, which consisted of a thin silk thread supporting a wax-covered straw (thin, very light reed or grass) with a small pith ball suspended on one end. The straw was balanced and suspended in an enclosed jar to prevent air drafts from affecting the results. His torsion balance could measure a force of only 1/100,000 of a gram by gauging the twist of the thread. There were markings around the circumference of the jar so Coulomb could measure, in degrees, any changes in the ball's position. Coulomb then used static electricity to charge the pith ball on the straw and another pith ball outside the jar. He brought the outside charged ball close to the jar. The ball inside the jar was repelled. He measured the distance of its movement on the degree markings on the jar and compared it with the distance between the centers of the inner and outer balls. He discovered that one of the basic laws of science applied (the inverse square law). When moving the outer ball twice the distance away from the inner ball, the effect on the inner ball was not one-half its movement but one-fourth. In other words, the effect of the electrical charge decreased as to the square of the distance between the centers of the charged balls.

Although Coulomb was given credit for demonstrating the effects of the "inverse square law" he was not the first to do so. Several other scientists, including Joseph Priestley and Daniel Bernoulli, of the early eighteenth century tried to find evidence of the inverse square law but failed. In the 1760s Henry Cavendish demonstrated the effects of the inverse square law experimentally. Unfortunately, the results of his experiments were not published until 1879. The law is really an analog of Sir Isaac Newton's law of gravity that is $F = G[m_1 \times m_2]/d^2$, where the F is the force, G is gravity, m_1 and m_2 are the masses of the two bodies that are involved, and d^2 is the square of the distance between the masses. Coulomb's law for electrical charges between two bodies is similar: $F = k[_1 \times q_2]/d^2$, where k is the electrical charge, q_1 and q_2 are the magnitude of the charges of the two bodies, and d^2 is the square to the distance between to two bodies. Or it can be written as the force between two charged particles as: $F = qq'/kd^2$ where F is the force, q and q' are the two charged particles, k is the dielectric constant, and d^2 is the distance between the two particles. It should be mentioned that electric and magnetic forces are four million, trillion trillion trillion times stronger than the force of gravity. Gravity is one of the weakest forces known, but it exists on a cosmic scale.

Coulomb's theory of the relationship between electricity and magnetism: *Electricity and magnetism follow the same physical laws, including the inverse square law.*

Coulomb demonstrated the similarity of the attractive and repulsive forces for electricity and magnetism and concluded that both were similar physical phenomena that followed the same physical laws. (See Figure A1 under Ampère.) Coulomb also concluded that electrical charges follow the same inverse law as does gravitation. Even so, many scientists of his day rejected this theory. When the theory of electromagnetism was later refined and better understood, it became important for the development and use of electromagnetic devices, such as motors and generators.

Coulomb's law of electrical charge: *The attractive and repulsive forces for electricity are proportional to the products of the charge.*

This famous theory is now known as Coulomb's law, which states that a coulomb is the unit quantity of electricity carried by an electric current of 1 ampere in 1 second. The unit of electrical charge, the coulomb (C), is named after him. As a result, a much better understanding exists of how to quantify electricity as a measurable current forced through a conductor by a voltage differential.

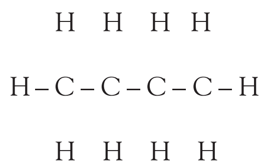
See also Cavendish; Faraday; Maxwell

COUPER'S THEORY FOR THE STRUCTURE OF CARBON COMPOUNDS:

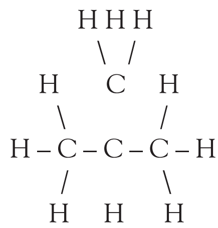
Chemistry: *Archibald Scott Couper* (1831–1892), Scotland.

> *Carbon atoms have the unique ability to bond their valence electrons together to structure both chains and branches of chains to form carbon compounds (mostly organic).*

Couper knew carbon must have four valence electrons because it could form inorganic compounds such as carbon dioxide, CO_2, where oxygen has a valance of 2. Thus, it takes only one carbon atom with a valence of 4 to join with two oxygen atoms to form the molecule O=C=O (Note: the two = represents two valence electrons joining the single carbon atom with two oxygen atoms). Further research indicated that carbon atoms have the unique ability to bond with other carbon atoms to form chains and branches (*see* Figure V3.) Couper was the first to use notations such as =C=C=C= for carbon atoms to illustrate his theory, advancing the concept of isomers, which are compounds with the same molecular formulas but are structured differently. Isomers have different chemical and physical characteristics due to different arrangements of the elements making up the molecules. The greatest variety of isomers is found among the various hydrocarbons and the many complex organic compounds. A typical example is the hydrocarbon isomer of C_4H_{10} that can be structured as a chain of 4 carbon atoms with 10 attached hydrogen atoms, or a different structure of a branched group of 4 carbon atoms, with 10 hydrogen atoms attached to the carbon atoms.



butane



2-methyl-propane

Their physical and chemical characteristics are quite different. The entire chemistry of carbon isomers, while complicated, has pioneered many new medicines and useful products.

Couper wrote an important paper titled "On a New Chemical Theory" in 1858 that explained his concepts of chemical compounds, but publication was delayed. In the meantime Fredrich Kekule arrived at similar isomeric straight chain and branching carbon molecular structures. However, after a dream of a snake eating its tail (see Figure K1), Kekule came up with a carbon ring structure that solved the problem of how some carbon compounds, including benzene, are formed in connecting rings. Even though Couper's designs for carbon compounds and isomers involved only straight and branching chain molecules, they anticipated and preceded Kekule's work.

See also Kekule; Van't Hoff

CRICK–WATSON THEORY OF DNA: Biology: *Francis Harry Compton Crick* (1916–2004), England. Francis Crick shared the 1962 Nobel Prize in Physiology or Medicine with James Watson and Maurice Wilkins.

> *DNA is a double helix joined by pairs of nucleotides of adenine + thymine (A+T) and guanine + cytosine (G+C), with the sugar-phosphate structure attached to the outsides of the helix strands.*

Early in Crick's career in England, he was joined by an American James Watson (1928–), who suggested that the first step in determining the structure of the basic molecule of life would be to learn more about its chemical nature, which they then pursued together. Crick and Watson were not the only scientists searching for the holy grail of life. Others, such as Maurice Wilkins (1916–2004) and his assistant, Rosalind Franklin, as well as the Nobel Laureate and Scottish biochemist Alexander Todd (1907–1997) in England, Erwin Chargaff, and Phoebus Levene in the United States, were conducting similar research.

There is a history of a number of scientists investigating the origins of replication of the DNA molecule. Frederick Griffith (1871–1941), a British medical officer, produced the first evidence of DNA when he experimentally identified the transformation of S and R strains of a bacterium. The Canadian-American physician and researcher Oswald Avery (1877–1955) experimentally proved that DNA was the transferring

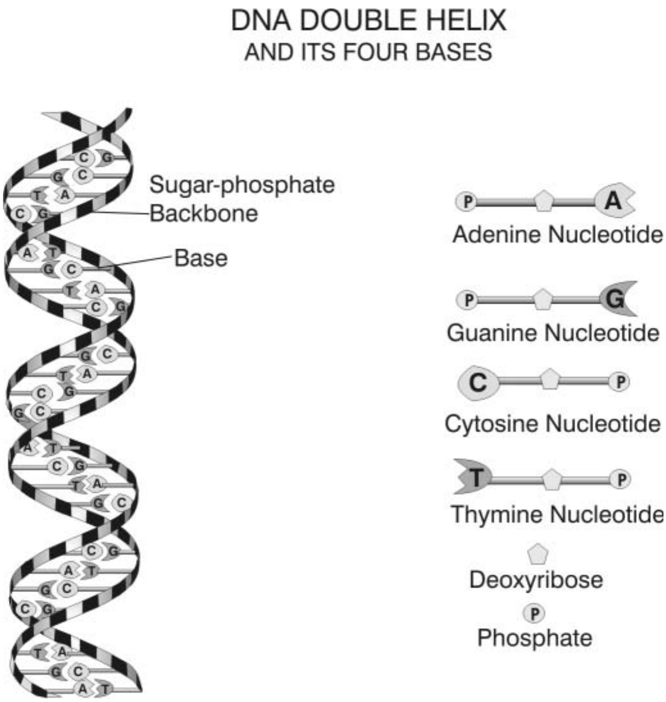


Figure C5. Crick and Watson determined the shape of the double helix shape for the DNA molecule from the crystal X-rays made by Rosalind Franklin.

agent for genetic information. And, Linus Pauling, who worked with the nature of chemical bonding, described the complex protein molecules (DNA) involved in the chromosomes of cells as being an alpha-helix structure, which came close to describing the double-helix structure proposed by Crick and Watson.

Nationalism, competition, jealousy, and secrecy, all of which are the antithesis of scientific investigations, were part of the search for the structure of DNA. Crick's work depended on information he obtained from crystallographic X-rays (X-ray photos) of DNA crystals to determine its structure (see Figure C5.) Franklin was very secretive about her work and refused to share her photographs or her crystallography techniques. Her supervisor, Wilkins, considered the study of DNA a joint project between Franklin and him. Franklin also withheld information about the placement of the sugar-phosphate backbone for the DNA molecule. Crick was acquainted previously with Wilkins, and as the story goes, there may have been a break in trust when Wilkins provided Crick with some of Franklin's vital information that enabled Crick to succeed with his project. In 1953 Crick and Watson completed their model based on information known at that time.

Francis Crick proposed a rather controversial hypothesis in his book *Astonishing Hypothesis: The Scientific Search for the Soul* in 1994. The hypothesis in essence states: *That a person's "you," your joys and your sorrows, your memories and your ambitions, your sense of personal identity and free will are in fact no more than the behavior of a vast assembly of nerve cells and their associated molecules.*

Humans have always wondered about their ability to be aware of themselves and attributed this phenomenon and their many personal thoughts, including beliefs in supernatural powers separate from their bodies. In the early seventeenth century René Descartes came up with the idea that the mind contains the essence of a human being and was distinct and separate from the brain and body. It was not until the discovery of the double helix of DNA that most scientists gave up the idea that consciousness, and so on, was too philosophical to study. Science experiments have indicated that all aspects of our subjective selves, our awareness, and all aspects of the mind are best explained by the behavior of over fifty billion nerve cells in the brain. Even today, not all scientists consider the mind, consciousness, and "self" as existing as a neurological phenomenon of the brain's multitude of neurons.

Crick and Watson shared the 1962 Nobel Prize for their discovery along with Wilkins, but Rosalind Franklin, being deceased, was not included. (Some say Franklin was not given adequate credit for her contributions to the final outcome.)

See also Chargaff; Franklin (Rosalind); Pauling; Watson

CROOKES' RADIATION THEORIES: Physics: *Sir William Crookes* (1832–1919), England.

Crookes' radiometer: *A closed glass container in which most of the air has been evacuated will continue to radiate heat.*

From his spectrographic work in identifying the element thallium, Crookes noticed that heat radiation caused unusual effects on the thallium gas while in the sealed glass container. He designed a device with four vanes. One side of each of the four vanes was painted black, and the other sides of the vanes were polished like a mirror. The vanes were balanced on a vertical pivot in a closed glass in which most of the air had been removed. When heat radiation (sunlight) struck the vanes inside the glass bulb, molecules on the dark hot side had greater momentum and thus pushed the vanes backward to a greater extent than did the molecules from the cooler shiny side. This led to further investigation of the effects of electricity on low-pressure gases. At the time, the radiometer demonstrated the essence of kinetic energy of gas molecules. Today, Crookes' radiometer is more like a toy used to demonstrate the effects of radiant heat on dark and shiny surfaces.

Crookes' cathode ray tube: *The air will glow when an electric current is passed through a closed glass tube containing low air pressure.*

To demonstrate that the glow in the Crookes tube and the slight fluorescence on the inner walls of the tube were due to electricity, Crookes placed a Maltese cross in the path of the rays. The form of the Maltese cross was used because its symmetrical design would produce a recognizable image as it interrupts the flow of cathode rays. At the point where the rays were blocked by the cross, a distinct shadow-like pattern appeared on the end of the glass tube.

Crookes also demonstrated that a magnet brought near the glass tube would deflect the cathode rays in a curved pattern that suggested the rays were composed of particles with an electric charge. He concluded it was impossible for electromagnetic radiation, such as light, to carry an electric charge and be deflected by a magnet. Therefore, the cathode rays must be charged particles. J. J. Thomson later demonstrated the cathode rays were really electrons. The shadow of the Maltese cross in Crookes' cathode ray tube might be considered the first TV picture because a similar process is used in modern television receivers.

See also Thomson

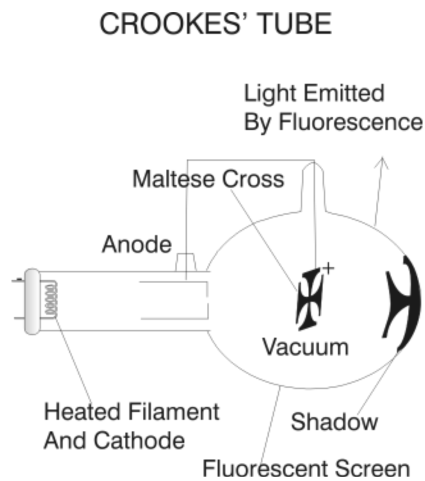


Figure C6. The symmetrical Maltese cross design was used to demonstrate that when a stream of electrons was sent to a target in the path of a fluorescent screen, the metal cross would block the screen. The shadow of the cross on the screen prevented the electrons from producing light on the fluorescent material on the screen. A similar device was used to demonstrate the nature of the electron; it has a negative charge and a magnet can deflect its path. Its mass is just 1/1840 the mass of the hydrogen atom.

CRUTZEN'S THEORY OF OZONE DEPLETION: Chemistry: *Paul Crutzen* (1933–), Netherlands. Paul Crutzen, along with Mario Molina and F. Sherwood Rowland received the 1995 Nobel Prize for Chemistry. Crutzen demonstrated that nitrogen oxide accelerated the destruction of ozone (O_3) in the stratosphere, while Rowland and Molina, two American chemists, discovered in 1974 that CFC gas (chlorofluorocarbon) also causes ozone depletion.

Crutzen's theory states: *Nonreactive nitrogen dioxide (N_2O) gas is lighter than air, thus it rises in the atmosphere where solar energy splits it into two different reactive compounds (NO and NO_2) where they react as a catalyst with ozone gas (O_3) breaking it into O_2 and atomic oxygen, thus causing a depletion of the original ozone.*

These three scientists were not the first to arrive at the chemistry related to the ozone-oxygen cyclic reactions. In 1930 Sydney Chapman, a British astronomer and geophysicist who is best known for his work with the kinetic theory of gases (see Chapman), wrote an article that explained how ultraviolet radiation (UV) breaks stratospheric oxygen (O_2) into oxygen atoms (O) which then combine to form ozone (O_3), followed by the formation of two oxygen molecules ($2O_2$) when the oxygen atoms recombine with the ozone. At that time Chapman was unaware that there was a catalytic action that drove this sequence.

Paul Crutzen knew that nitrous oxide (N_2O), a stable gas produced by some soil bacteria (and later identified as a gas produced by automobile exhausts, jet airplanes, and fertilizers), could change into nitric oxide (NO) in the stratosphere that, in turn, acts as a catalyst and contributes to ozone depletion.

In 1974 Frank Sherwood Rowland and Mario J. Molina were the first to arrive at the idea that chlorofluorocarbons (CFCs) would have the same catalytic effect on the ozone molecule, as did nitrous oxide as proposed by Chapman. It was discovered that most of the CFCs produced since the 1930s were still in the atmosphere due to its high degree of stability. It was determined that UV light dissociates the CFCs and releases chlorine (Cl) in the ozone layer and is thus more effective in breaking down the ozone molecule than is nitrous oxide.

A number of other scientists became involved in the chemistry of ozone, but it was not until 1985 that Joe Farman, Brian Gardiner, and Jonathan Shanklin with the British Antarctic Society (BAS) published a paper in *Nature* that announced the discovery of a "hole" (more accurately a thinning area) in the ozone over Antarctica. Later a less extensive "hole" was discovered over the North Pole as well. Ozone is not really a "layer" but rather a diffuse screen of gases at an altitude of about 35 kilometers that partially blocks harmful ultraviolet radiation from reaching Earth's surface. Ozone is produced in the warmer stratosphere over the equator and drifts toward the poles. Crutzen showed that ozone is continually created and destroyed in the stratosphere. The concentration of ozone is also affected by natural processes such as volcanoes, atmospheric temperatures, and variations in solar activity so that, to some extent, it is replenished, but less so over the colder polar regions. The size of the "holes" over the poles varies with temperatures at different times of the year. A simplified depiction of the chemical reaction follows:

$$O + O_2 \rightarrow O_3$$
$$UV + O_3 \rightarrow O_2 + O$$

Ozone reacts to many things in the atmosphere such as nitrous oxide, several halogens (chlorine and bromine), methyl chloride, as well as hydrogen, where they capture an oxygen atom from the ozone molecule. An "X" is used as a generic chemical symbol to represent any substance that can react with ozone as follows:

$$X + O_3 \rightarrow XO + O_2$$

The great increase in the use of CFCs for refrigeration and pressure in spray cans over the years is held responsible as possibly the main cause of ozone depletion. In 1996 several nations began phasing out the production of CFCs, halogens, and related chemicals that seems to have affected the size of the ozone "hole." It might be noted that the "ozone hole" has recently been significantly decreased. This may also be a result of a "natural cycle" related to the formation and destruction of ozone, or it may be a result of several nations banning the use of CFCs.

See also Chapman; Rowland

CURIES' RADIATION THEORIES AND HYPOTHESES: Chemistry: *Marie Sklodowska Curie* (1867–1934), France. Marie and Pierre Curie shared the 1903 Nobel Prize for Physics with Antoine Henri Becquerel (1852–1908), who discovered spontaneous radioactivity. Madame Curie was also awarded the 1911 Nobel Prize for chemistry for her discovery of radium and polonium. She is one of only four people ever to receive two Nobel Prizes (the other three are L. Pauling, J. Bardeen, and F. Sanger).

Curies' radiation hypothesis: *Chemical reactions and mixtures of uranium with other substances do not affect the level of radiation. Only the quantity of uranium determines the level of radiation. Therefore, radioactivity must be a basic property of uranium.*

Pierre Curie (1859–1906) jointly received the 1903 Nobel Prize for Physics with his wife Marie, and Antoine Henri Becquerel. He determined that the slight deformation caused by the squeezing of opposite sides of certain types of ceramic crystals produces opposite electric charges on opposite faces of a crystal.

Pierre Curie was a well-known physicist who assisted his wife, Marie, in her research with radioactive elements. With his brother, Jacques Curie (1856–1941) they developed several techniques for detecting and measuring the strength of radiation. Their instrument, the electrometer, was sensitive enough to produce an electric current between two metal plates separated by the radioactive sample. They also discovered piezoelectricity, from the Greek work *piezo* meaning "to press." The piezo effect occurs when certain types of crystals are put under pressure. Pierre Curie and his brother also discovered it would work in the opposite manner, that is, by applying an electric charge to a crystal a change in the crystal's structure occurs. This discovery was incorporated in their electrometer used to measure minute electric currents, as well as radiation. The piezoelectric effect has found many useful applications including crystals in crystal microphones, sonar, ultrasound devices, phonograph needle pickup devices, radio transmitters, and as an analogous pendulum in timepieces. It is now found in many types of watches, clocks, and other devices where regular mechanical vibrations of a quartz crystal are used.

Pierre Curie also measured the amount of heat given off by radium. Each gram of radium gives off 140 calories of heat per hour, with a **half-life** of about sixteen hundred years. The Curies realized this amount of energy was beyond normal chemical reactions and must be from some other unknown part of the atom. Thus began the age of nuclear energy, even though the nuclei of atoms had yet to be discovered. Pierre Curie also discovered that permanent magnets lose their magnetism when heated to a specific temperature. This temperature point is now called the *Curie temperature* as a unit of measurement.

At the time the Curies worked with radiation, particularly radium, the extent of the dangers of radiation was unknown. It is assumed the Curies may have been the first humans to suffer from radiation sickness, but Pierre died after an accident with a horse and carriage. Marie died from illnesses related to radiation poisoning. The *curie*, the unit measurement for radioactivity, was named for Pierre Curie. Marie Curie's notebooks are still considered extremely radioactive.

Madame Curie separated chemicals from uranium minerals and found the ore pitchblende was more radioactive than uranium earth itself. Pitchblende is a heavy black ore containing a yellow compound that the German chemist Martin Heinrich Klaproth (1743–1817) thought was a new element. He named it *uranium* after the planet Uranus. The Curies brought many cartloads of pitchblende from northern Europe to her laboratory shed in France. (Pitchblende is also found in Colorado, Canada, and Zaire.) Over a period of months, Curie and her assistant chemically extracted this new element. She also theorized there must be more than one type of radioactive element in the ore, leading to a new hypothesis.

Curie's hypothesis for new radioactive elements: *Because the pitchblende ore contained substances with greater radioactivity than uranium, pitchblende must contain new radioactive elements.*

Curie continued to separate and test these new substances, which proved to be new elements. She named one polonium after her native country (Poland), and the other radium, for its high radioactivity. She discovered that the heavy metal thorium also exhibited radiation. Curie is credited with coining the word "*radioactivity*." She and her assistant used several chemical processes to separate the radium, which exists in very small amounts in pitchblende. After many months, she had produced only about 0.1 gram of radium chloride.

See also Becquerel

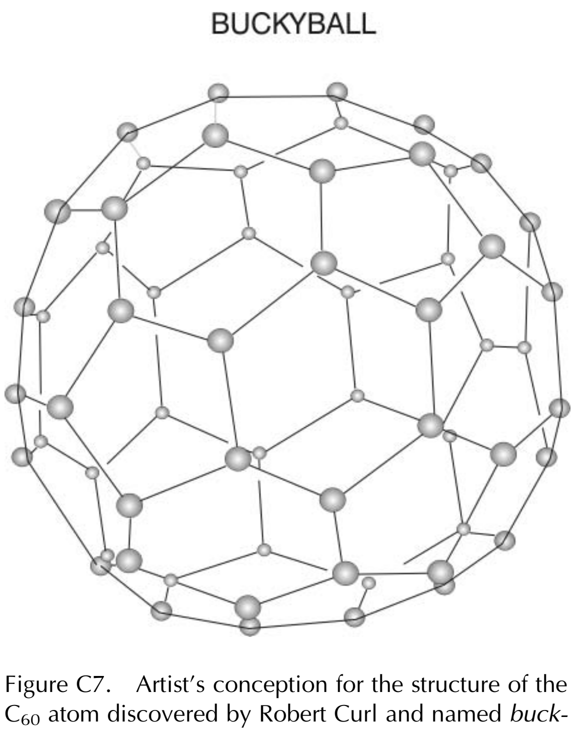


Figure C7. Artist's conception for the structure of the C_{60} atom discovered by Robert Curl and named *buckminsterfullerene* (nicknamed *Buckyballs*) by Harold Kroto. These compact masses of carbon are a third form of pure carbon, each composed of 60 carbon atoms into a soccer ball shape by 20 hexagons and 12 pentagons of bonded carbon atoms.

CURL'S HYPOTHESIS FOR A NEW FORM OF CARBON: Chemistry: *Robert F. Curl, Jr.* (1933–), United States. Robert F. Curl, Richard E. Smalley, and Sir Harold W. Kroto jointly received the 1996 Nobel Prize for Chemistry.

Curl's C_{60} hypothesis: *Vaporized carbon atoms in a vacuum can form single and double bonds, similar to aromatic carbon compounds, to produce a symmetrically closed shell with a surface consisting of multiple polygons.*

Curl and Smalley discovered the new complex carbon molecules, called fullerenes in 1985 while they were at Rice University in Houston, Texas, and Kroto was at the University of Sussex in England. The most common form is a group of 60 atoms shaped similar to a soccer ball, which is formed by 20 hexagons and 12 pentagons of bonded carbon atoms (*see* Figure C7). Due to the geodesic shape of the surfaces it was named *buckminsterfullerene,* after the architect R. Buckminster Fuller, who designed geodesic dome structures. However, it is usually referred to by its nickname, *Buckyballs.* Additional complex ball-shaped molecules of bonded carbon have been developed in addition to C_{60}. They include C_{69}, C_{70}, C_{76}, C_{78}, and C_{80}.

The discovery of fullerene Buckyball molecules has opened up new research vistas in the areas of superconductive materials, plastics, polymers, and medicines, as well as new theories to explain the beginning of the universe and the structure of stars.

See also Kroto

Robert F. Curl's life is an example of how parents and teachers can exert a positive influence on a young person's life. His father was a minister who traveled around to different churches in various towns in Texas. At the age of nine Curl's father became a church administrator and finally settled in one place. At that time, his parents gave him a chemistry set and a short time later Curl decided on a career as a chemist. He excelled in most subjects, but mainly in science. However, he was unable to take a class in chemistry until high school where his teacher recognized his outstanding interest and ability in this field. Curl was so far ahead of his class that his teacher assigned him special projects that he devoured. One of his early projects was a working model of a Cottrell precipitator, which is used in industrial smoke stacks to eliminate minute particles from the exhaust. He chose Rice University in Houston for its programs for students like himself, and his parents approved his choice because Rice did not charge tuition. He enjoyed his professors and did well in his first and second year and by his third year he was deeply involved in physical and organic chemistry, taught by some outstanding professors. He did his graduate work at the University of California at Berkeley with several outstanding professors. Curl said that his years at Berkeley were his most happy years. This is also when he met and married his wife. He did experimental as well as theoretical work on silicon oxides. Following Berkeley, Curl was appointed to a postdoctoral position at Harvard. Harvard was followed by an appointment as assistant professor at Rice University where he continued research in physical chemistry. Curl collaborated with several outstanding people who contributed to the discovery of fullerenes (Buckyballs). As a result of this research, Robert Curl, Rick Smalley, and Harry Kroto were awarded the 1996 Noble Prize for Chemistry.

CUVIER'S THEORIES OF ANATOMY AND TAXONOMY: Biology: *Baron Georges Leopold Chrétien Frédéric Dagobert Cuvier* (1769–1832), France.

Cuvier's classification of animals: *Based on functional integration of animals there are four classes or "branches": 1) vertebrata (with backbones; e.g., mammals), 2) articulata (arthropods; e.g., insects), 3) mollusca (bilateral symmetrical invertebrates; e.g., clams), and 4) radiata (radially symmetrical sea animals; e.g., echinoderms).*

Cuvier demonstrated how the anatomy of different animals compared with one another and proposed these four **phyla** of animals in his classification scheme. Cuvier is often referred to as the founder of the science of comparative anatomy.

Cuvier's concept of form and function: *All organisms are integrated wholes into which parts are formed according to their functions.*

Cuvier was a firm believer that form follows function, not the reverse. Generally this means that the structure of tissue or an organ is based on what function the tissue or organ is required to execute. He believed that if a part of an animal changed, it would change the entire animal's form. He stated that all the parts of each animal are arranged to make it possible for the animal to be complete. Thus, he rejected organic evolution. The concept of form follows function is, to some extent, still debated in modern biology. The concept is also used in the field of architectural design, particularly by followers of the American architect Louis Henri Sullivan's (1856–1924) philosophy that a building's form should be designed to represent its intended function. In other words, for biology and architecture the structure should be built for the purposes of the organism it surrounds.

Cuvier's theory of evolution: *Organic evolution cannot exist because any change in an organism's structure would upset the balance of the whole organism, and thus it would be unable to survive in its environment.*

Cuvier rejected Darwin's theory of organic evolution based on natural selection that results in changes in species and the emergence of new species over long periods of time. Cuvier believed similarities between and among different organisms are due to common functions of their parts, not evolutionary changes. However, he did believe that catastrophic events occurred on Earth (he preferred the term "periodic revolutions"). Natural disasters such as floods, fire, and earthquakes caused massive extinction of animals and provide situations for the arrival of new species. Niles Eldredge and the late Stephen Jay Gould revived the catastrophic theory as *punctuated evolution*.

Cuvier's theory of fossils: *Fossils represent ancient species that became extinct due to period revolutions in their environment.*

In his study of fossils, Cuvier recognized some fossils were found deeper in the strata of rocks and earth and that the depth of the strata could determine their age. He used a similar classification system for fossils as his four phyla for living animals. Cuvier also recognized the detailed structure in some fossils, particularly the structure of wings. He was the first to identify the fossil of a flying reptile he named *pterodactyl.* Cuvier has been referred to as the founder of paleontology.

See also Buffon; Darwin; Eldredge–Gould; Gould; Lamarck; Wallace

D

DAGUERRE'S CONCEPT OF HOW TO "FREEZE" IMAGES MADE BY THE CAMERA OBSCURA: Chemistry: *Louis-Jacques-Mandé Daguerre* (1789–1851), France.

> *A light sensitive plate exposed to mercury vapors will change a latent image to a visible image.*

Daguerre was a French chemist as well as an artist who is sometimes credited with the discovery of photography, although several other competitors worked on the process contemporaneously. Daguerre and his assistants painted large scenes (14 × 22 meters) to use in dioramas for stage productions. The term "diorama" was coined by Daguerre in 1822. It refers to a rotating three-dimensional model or display of a landscape that depicts historical events, but with a faulty perspective. Changing the lighting as well as the scenes produced illusions of famous landmarks. These shows were famous in Paris and London and were in great demand. Initially, Daguerre traced images made by a camera obscura (a pin-hole camera that produced an upside-down mirror image of a scene) to copy for their dioramas.

Because this was time-consuming work, he theorized that there must be a method of "freezing" the camera's image, thus eliminating the laborious process of tracing. After some experimentation, Daguerre silver coated a copper plate. At the time, it was known that some salts of silver, such as silver iodide, were light sensitive. During one such experiment he left an exposed plate in a cabinet with a broken mercury thermometer. Later when he retrieved the plate, he observed that the latent image was now visible, but as a reversed, and more-or-less, negative image. Later experiments indicated that an image could be formed after just a few minutes exposure and that these images could be "fixed" in seawater. When left in daylight, the image faded, so Daguerre and his assistants attempted to secure the image in a "fixer" chemical known as hyposulfate

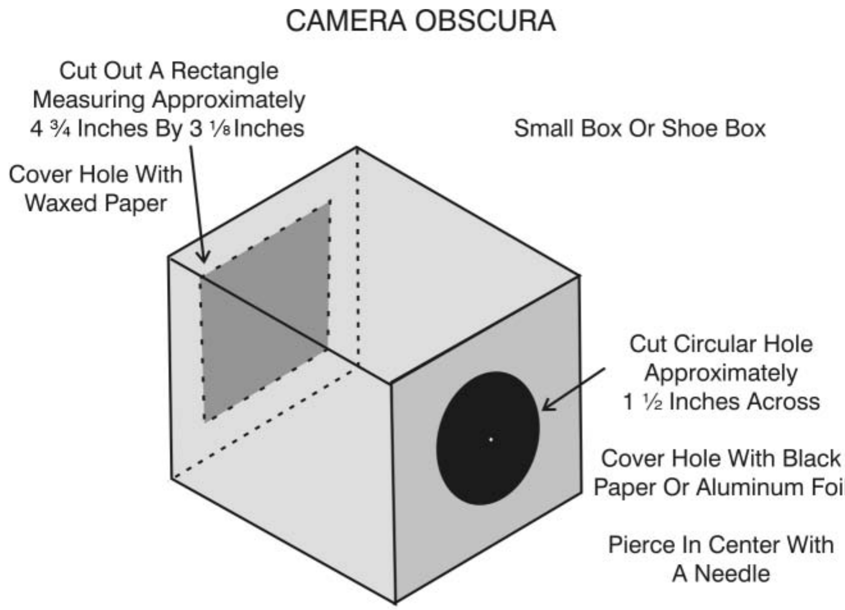


Figure D1. How to make a simple "box" camera.

of soda or "hypo." (The same form of hypo is still used today to dissolve the unexposed silver salts from the negative film or paper print so that it is no longer light sensitive.) The result was the "daguerreotype" positive image, which had to be enclosed in a glass frame with an inert gas such as nitrogen to prevent further fading. Some of these images still exist.

By the early 1800s daguerreotype photography had spread to the United States where it became popular with the masses as an inexpensive portraiture process. There were several disadvantages to daguerreotype photographs. They produced a positive and reversed image. It required a few minutes exposure. The image was not particularly permanent, nor could copies be made of the image. Even though Daguerre received patents for his process in England and Wales, the French government purchased the process from him and then gave it to the world without charge. At the same time William Henry Fox Talbot (1800–1877) of England (sometimes given credit as the discoverer of modern photography) was also working on a similar process for use as an entertainment medium. Other processes, such as the ambrotype, tintype, and collodion, of the mid-1800s were improvements over the daguerreotype. However, it was the introduction of the system that could produce a negative on a thin glass plate by the wet collodion process developed by Frederick Scott Archer (1813–1857) that was the beginning of the end of daguerreotypes. Archer's process produced a negative that, when developed and fixed, could be used to make positive prints that were superior to daguerreotypes. The improvement of this negative-to-positive process of photography proved the demise of daguerreotypes. Photography has progressed from the pinhole camera to the daguerreotype, to negative/positive films and paper, to cameras of today that produce digital images that require no negative film.

DALE'S THEORY OF VAGUS NERVE STIMULI: Biology: *Sir Henry Hallet Dale* (1875–1968), England. Sir Henry Hallet Dale and Otto Loewi shared the 1936 Nobel Prize for Physiology or Medicine.

Chemical and electrical stimuli are responsible for affecting nerve action.

While at the Wellcome Physiological Research Laboratories in England, Henry Dale discovered that the dangerous ergot fungus contained the chemical acetylcholine, a pharmacologically active extract that acts as a neurotransmitter. Later, along with the German American physician and pharmacological researcher Otto Loewi (1873–1961), Dale demonstrated that acetylcholine could stimulate and affect the parasympathetic nervous system that is responsible for controlling various organs. Acetylcholine is an **alkaloid** that poisons animal tissue. Eating spoiled grain that contains this fungus can result in a serious disease called *ergotism*. The symptoms are a burning sensation in the limbs that may lead to gangrene, hallucinations, and convulsions. It has been known to cause epidemics among poorer populations who eat rotting rye grain. Outbreaks of ergotism in the Middle Ages were called St. Anthony's fire. Along with the plague and scurvy, it caused psychic epidemics, with symptoms of dancing manias and mass madness where people claimed to be possessed by the devil, often ending in the killing of Jews, children, and women who were called "witches."

Dr. Loewi identified a chemical substance extracted from the vagus nerves of frogs that he called *vagusstoffe*. Dale recognized that it was similar to acetylcholine produced by ergot, which he associated as the same chemical resulting from the electrical discharge that stimulates the nervous system. Dale hypothesized that the electrical stimulation and acetylcholine were involved in controlling the heartbeat rate of humans and the nerve responses for other organs. This discovery that acetylcholine is a chemical released from **autonomic** nerve endings led to a better understanding of the electrochemical nature of the nervous system and the development of drugs similar to acetylcholine to control heart abnormalities.

Dale also explored the physiological affects of histamines and similar substances and their effects on human allergies. His work later led to the development of antihistamines used to relieve symptoms from hay fever and similar allergies.

D'ALEMBERT'S PRINCIPLE OF FLUID DYNAMICS: Mathematics and Physics: *Jean le Rond d'Alembert* (1717–1783), France.

The sum of the differences between the generalized forces acting on a solid or fluid system and the time derived from the motion of the system along an infinitesimal displacement of the system is zero.

D'Alembert's principle, a classical mechanics and dynamic systems concept, is somewhat difficult to understand without knowledge of mathematics and the concepts of "internal force" and "internal torque," both static and in motion (as in fluids). Any moving body is subjected to internal forces and torques caused by its rotation. This can be considered as something like an extension of Newton's third law of motion (where every action has an equal and opposite reaction) and Newton's law of angular acceleration that is only measured from the center of a mass. The difference is that for

D'Alembert's principle the inertial torque can act at any point within the mass, not just from the center as for Newton's law of angular acceleration. The sum of torques (including the inertial moment and force) as applied to any point is expressed in the equation $\Sigma\ T = 0$, where Σ is the sum, T is the torque, and 0 is zero.

D'Alembert was the illegitimate son of a rather well-known French army officer, the chevalier Louis-Camus Destouches. After his birth, his mother abandoned him at a church. He was later sent to an orphanage. Soon after, he was adopted by a workman and his wife who raised and educated him with funds secretly provided by D'Alembert's natural father. Educated by a religious group, he rebelled against an ecclesiastical career and chose instead a career in law, graduating as an advocate in 1738. He had broad interests and explored medicine and mathematics. In 1739 he pointed out mistakes in computations and equations he found in a popular mathematics publication. In 1740 he published his work in fluid mechanics that also explained his ideas on refraction, as well as his more famous D'Alembert's paradox that describes that the drag on a solid body that is within an incompressible fluid will be zero. He made one great error in the field of statistics when he published his argument that the probability of a tossed coin landing "heads" increases for every time that it comes up tails. His system led to a belief that when gambling one should bet less as one is winning and bet more if losing. Today, it is rather common knowledge that the statistics related to probability states that the odds of an honest coin coming up heads or tails is 50% for each side of the coin for each and every time the coin is tossed. This does not mean that the results might come up several heads or tails over several tosses—but rather each toss has a 50/50 chance of ending as heads or tails.

D'Alembert made several other contributions to mathematics, mainly writing most of the mathematics and scientific articles as editor of the huge twenty-eight-volume *Denis Diderot's Encyclopedia*. He also developed a theory of partial differential equations, a theory of winds, and the harmonics of vibrations. He also published eight books on his mathematical studies.

D'Alembert was in poor health later in life and died of a urinary disease. Because early in life he had rebelled against his religious education and background, he became a life-long nonbeliever and thus was buried in a common grave.

DALTON'S LAWS AND THEORIES: Chemistry: *John Dalton* (1766–1844), England.

Dalton's law of partial pressure: *At an initial temperature, the individual gases in a mixture of gases expand equally as they approach a higher temperature.*

Another way to say this is that all gases in a mixture of gases expand equally when subjected to equal heat. Because this relationship cannot be observed directly, it was established as a viable law by Dalton's observations and calculations dealing with his study of the atmosphere, humidity, dew point, and vapor pressure. This concept that all gases behave in a similar manner under similar temperatures led to other gas laws and Dalton's theories of the atom.

Dalton's atomic theory for elements: *1) The smallest particles of all matter are atoms; 2) Atoms are indivisible particles that cannot be either created or destroyed; 3) Atoms of the same element are the same; 4) Each element has its own type of atoms; 5) Atoms of one element cannot ever be changed into atoms of another element.*

Dalton's atomic theory was based on Democritus' philosophical concepts. A main difference was that Dalton was more empirical and documented his observations. He based his ideas about the atom on concepts developed by the "gas chemists," such as Avogadro, Boyle, Charles, and Gay-Lussac.

Dalton's theory for compounds: *1) Chemical reactions occur when atoms of different elements are separated or arranged in exact whole-number combinations, and 2) compounded atoms (molecules) are formed by the joined atoms of the elements that make up the compound.*

Dalton used his observations and measurements to assert his theory of compounds. Although molecules were not yet identified, his concepts of atoms combining by weight and whole numbers remain essentially correct.

Dalton's law of definite proportions: *A specific chemical compound always contains the same elements at the same fixed proportion by weight.*

Dalton rationalized these laws were based on his theories for elements and compounds and on what was known about atomic weights at the time. The law of definite proportions led to his law of multiple proportions.

Dalton's law of multiple proportions: *When two elements form more than one compound by combining in more than one proportion by weight, the weight of one element will be in simple, integer ratios to its weight when combined in a second compound.*

This means that atoms of one element can combine in different ratios, by weight, with atoms of another element. Dalton's laws were in essence correct. The problem he had at the time his laws were formulated was that accurate atomic weights of elements were not known, nor was the concept of **valence** for atoms forming molecules. Regardless, his insight enabled him to formulate two major laws of chemistry: the laws of definite and multiple proportions.

Dalton conceived these laws from his knowledge that oxygen and carbon can form two different compounds with different proportions of oxygen and carbon. For example, CO_2 (carbon dioxide, with a 2:1 ratio of oxygen) contains twice the amount of oxygen than CO (carbon monoxide). Dalton assumed the composition and ratio of elements in all compounds would be the simplest possible. This led to a mistake when he tried to apply his law to the compound water molecule. He assumed the ratio was 1:1 for hydrogen to oxygen (HO). This error occurred because at this time in history oxygen was given the atomic weight of 7, while hydrogen was given the arbitrary weight of 1, because it was the lightest of the elements. Once water molecules were separated by electrolysis, it became obvious there was twice as much hydrogen gas (by volume) derived than oxygen gas. Therefore, the water molecule had to be composed of two molecules of hydrogen (by volume not weight) to one molecule of oxygen (2H + O) or (H_2O).

Dalton's atomic theory was a combination of old and new ways of looking at the chemical nature of the world. His concept of atomic weights and the combination of atoms by whole numbers laid the foundation for further research into the makeup of matter. His experimental approach to studying chemicals and systems provided important information for future scientists. Also, his empirical and experimental techniques and the habit of recording his results showed others how to proceed in a rational manner. Dalton used some old symbols for chemicals known from the days of ancient Greece, and he added some of his own which were later replaced by the symbols now used for the elements (*see* Figure D2).

Not all of Dalton's laws were well received until other chemists rediscovered Avogadro's theories dealing with particle relationships of gases, and Dmitri Mendeleev's Periodic Table based on the atomic weights of the then-known elements was accepted.

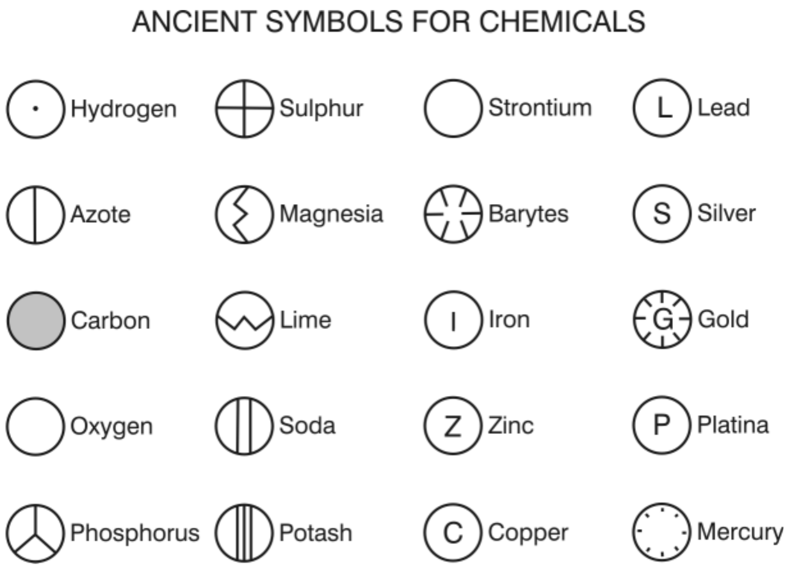


Figure D2. Ancient chemical symbols used by John Dalton.

(The Periodic Table of Elements was later revised according to the atomic *numbers* rather than the atomic *weights* of the elements.) Dalton's laws have been refined and improved over the years, but his work formed the central basis for modern chemistry. He is considered one of the fathers of modern chemistry.

See also Atomism Theories; Avogadro; Cannizzaro; Democritus; Dumas; Lavoisier; Thomson

DANA'S THEORY OF GEOSYNCLINE: Geology: *James Dwight Dana* (1813–1895), American.

> *A geosyncline is a gradual deepening of the ocean's basins that formed troughs or dips filled with sediments that were then compressed and folded to form mountain chains as the earth cooled and contracted.*

There are two kinds of geosynclines: 1) *miogeosynclines* (meaning "somewhat" like a geosyncline) are formed in shallow water at the edges of continents and are formed by sediments of sandstones, shales, and limestone that increase the thickness of continents. And 2) *eugeosynclines* (meaning "real" geosynclines) are rock formations in deeper ocean environments caused by submarine lavas from volcanoes erupting on the seafloor, and the formation of rocks such as slates, tuffs, cherts, greywackes, as well as igneous rocks formed from what are known as "plutons."

Many features of modern geology and mineralogy are built on Dana's scientific theories and concepts that are, for the most part, obsolete. These up-dated theories include midocean rifts and plate tectonics, revised concepts for the building of mountain ranges, volcanism, and similar geologic theories and concepts.

Dana was born into a middle-class family in the early 1800s. His father owned a hardware store in New York State. At a young age he had the "collecting bug" and

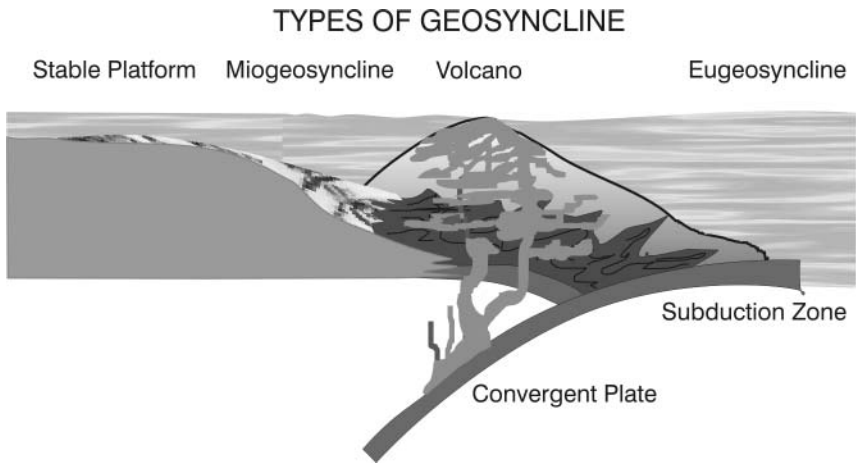


Figure D3. Examples of the two kinds of geosynclines: *Miogeosynclines* (means "like" a real geosyncline) and *Eugeosynclines* (meaning a real geosyncline).

spent much of his free time gathering rocks, insects, and plants. He attended Yale and studied under his future father-in-law Benjamin Stillman. At the age of 25 he was fortunate to be hired as one of several scientists on an expedition of six ships to explore and chart islands in the Pacific under Captain Charles Wilkes. At that time, the U.S. government needed to explore the Pacific for possible way stations for American merchant ships just as they needed to explore Antarctica for the whaling ships that ventured to this remote continent. This is one of the first examples of the government supporting a scientific venture. The expedition lasted five years and made many stops at the seemingly countless islands of the Pacific, including a visit to an active volcano of Kilauea in Hawaii. Soon after his return he married his former professor's daughter, the nineteen-year-old Henrietta Stillman.

Dana learned much on this voyage that he expanded and incorporated into the many scientific papers and books that he wrote throughout the rest of his life. His best known are *System of Mineralogy* (1837), *Manual of Mineralogy* (1848), *Manual of Geology* (1862), *Manual of Mineralogy and Lithology* (1887), *Corals and Coral Islands* (1872), and *Characteristics of Volcanoes* (1890). Several of these publications became well-known textbooks. One interesting publication in 1849 focused on the geology of the Sacramento Valley in northern California and the Umpqua River in Oregon where he mentioned the possibility of gold in these regions. It is said that this publication is partly responsible for the great gold rush of that period of history.

DANIELL'S CONCEPT OF THE ELECTRO-CHEMICAL CELL: Chemistry: *John Frederic Daniell* (1790–1845), England.

A two-fluid battery (cells) will produce a more reliable constant source of electricity over a longer period of time than will a single-fluid battery (cells).

John Daniell was not the first to try to artificially produce electricity by the "wet method." Luigi Galvani thought he discovered "flowing" electricity when he hooked up a dissected frog's spinal cord and legs with a copper hook that suspended the end of one of the legs to an iron railing. He mistakenly thought he had discovered "animal electricity" because the frog's legs moved. Later, Alessandro Volta was unable to find any electricity in the legs of frogs and then went on to disprove Galvani's claim of discovering "current" electricity. Volta dipped a disk of copper and a disk of zinc into a container of salt solution that acted as an electrolyte. He reasoned that by placing alternate disks of the two metals separated by cardboard that was soaked in salt solution and then attaching a wire on each end, he could increase the flow of an electric current. This was the first battery composed of several "cells." The term "volts" refers to the "electrical potential" or "the pressure behind the electric current (amps)." The major problem with the Volta cell/battery was that the electrolyte emitted hydrogen gas that collected at the copper disk (the positive pole) and soon formed a screen-like barrier that prevented the flow of current. Improvements were made including the use of dilute sulfuric acid (H_2SO_4) as the electrolyte. However, after one use the Volta battery had to be dismantled to stop its chemical reaction.

The Daniell cells were a great improvement in the development of portable sources of small amounts of electricity. They were not only more reliable but safer. Daniell cells are also referred to as "gravity cells" and a "crowfoot cell" when a particular shape of electrodes are used. The Daniell cell's electrolytes are zinc sulfate ($ZnSO_4$) and copper sulfate ($CuSO_4$). The chemical reaction that takes place produces about 1.1 volts of electricity. There are various designs for gravity-type Daniell cells, but basically the cell is composed of a central zinc metal cathode that is placed into a porous pot containing a zinc sulfate

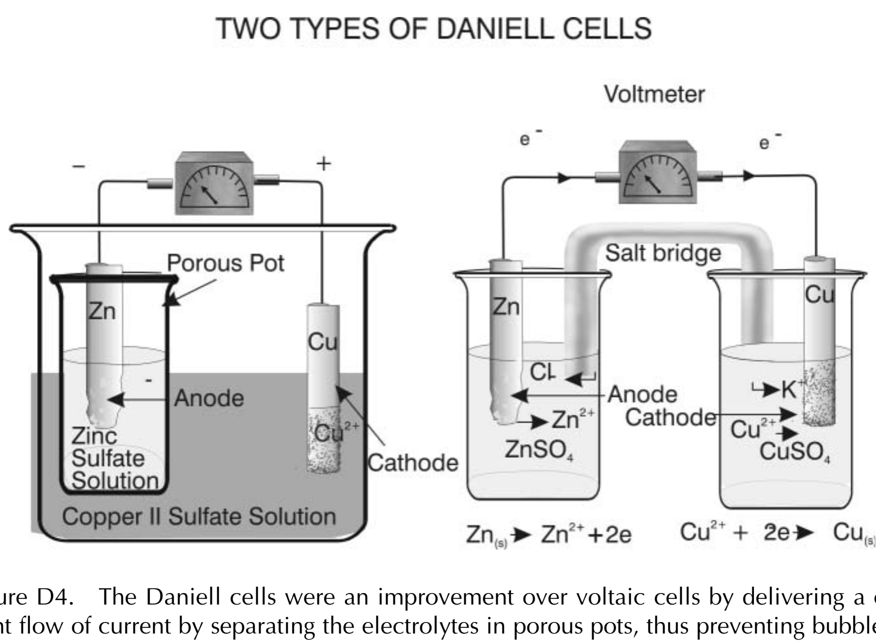


Figure D4. The Daniell cells were an improvement over voltaic cells by delivering a constant flow of current by separating the electrolytes in porous pots, thus preventing bubbles of hydrogen from forming on the electrodes.

solution. This porous pot is then placed into a solution of copper sulfate that is inside a copper container that acts as the anode. The purpose of the porous pot is for it to act as a barrier to separate the two solutions to prevent depolarization that would be caused by bubbles of hydrogen gas collecting at the anode. Unlike the Volta cell, the Daniell gravity cell can produce a continuous flow of electricity. Another version is known as the crowfoot cell that uses the difference in specific gravity (density) of the two solutions with the zinc sulfate layer over the copper sulfate solution. Each separated layer of electrolyte had its own electrode shaped like a crow's foot suspended in the solutions. Several versions of the Daniell cell were developed before the days of the "dry cell" (*see* Figure D4 for two modern versions of Daniell cells).

Although best known for his improved "wet" cell to produce electricity, John Daniell also had a career in meteorology. He invented the dew-point hygrometer known by his name, a pyrometer, and a water barometer. He also devised a way to produce gas that could be used for lighting purposes from a mixture of resin with turpentine. He wrote several articles on meteorology, climate, and chemical philosophy before his untimely death from apoplexy (stroke) at a meeting of the Royal Society in London in 1845.

See also Galvani; Volta

DARLINGTON'S THEORY OF CELL NUCLEAR DIVISIONS: Biology (Genetics): *Cyril Dean Darlington* (1903–1981), England.

> *Chromosomes in the first stages of normal cell division are divided by the process of mitosis, whereas the chromosomes are undivided in early stages of meiosis prior to gamete formation in the sex cells of male and females.*

Mitosis is the process of cell division in **soma** (body) cells whereas meiosis is the halving of the number of male and female chromosomes in their sex cells before recombining in the **zygote**. This concept was important for the understanding of how chromosomes "split" in the nuclei of cells.

Darlington is sometimes referred to as the man who discovered chromosomes. One of his contributions to the scientific theory of evolution was his discovery of exactly how chromosomes "cross over" during fertilization of the ovum (egg) cells by the sperm cells during meiosis.

A stern schoolteacher father and a firm bitter mother raised Darlington in a small town in Lancashire, England. He did not enjoy school, but as a six-foot three-inch young adult, he applied to an agricultural college, was turned down, but did receive a position as an unpaid technician. After the publication of his first scientific paper, he was hired by the John Innes Horticultural Institution of Merton, England. His mentors, the British geneticist William Bateson (1861–1926) and the British cytologist Frank Newton (d.1927) died within a year of each, and J.B.S. Haldane became head of the Innes Institute. Soon after, Haldane and Darlington became friends. As a consequence, Darlington became less hostile to authority and more self-confident in the academic environment and soon made his contributions to genetics. His first book the controversial *Recent Advances in Cytology* was published in 1932. It was not well accepted at first but later became known as containing the definitive science that described the mechanism of evolution observable at the chromosomal level. In 1937 he became director of the Innes Institute, and also a Fellow of the Royal Society.

Near the end of his career he cultivated an interest in the differences between races and how genetics might be applied to human history. He became involved in science and politics and condemned Russia for its practice of Lysenkoism over Mendelian genetics. During the last twenty-five years of his life he published a trilogy on genetics and humans, *Genetics and Man* (1953), *The Evolution of Man and Society*"(1969), and *The Little Universe of Man* (1978).

See also Haldane; Lysenko; Mendel

DARWIN'S THEORY OF EVOLUTION BY NATURAL SELECTION: Biology: *Charles Robert Darwin* (1809–1882), England.

> *Environmental pressures on organisms, such as climate and availability of natural resources such as food, act to select, by natural processes, those individuals better adapted to survive and who thus will pass viable traits related to survival to subsequent generations.*

In other words, natural selection is the force responsible for the development of advantageous traits in animals and thus plays the major role in the development of species. Modern concepts of evolution are as follows:

1. Different species of plants and animals vary in form and behavior. This variation is a basis for inherited characteristics.
2. Most species of plants and animals produce many more offspring than their environment can support.
3. Selected individuals of a species are better adapted to their environmental conditions than others and thus survive ("survival of the fittest"). Therefore, those individuals with the most favorable genes for survival will be the most "fit" for reproduction and pass these "survival" genes to offspring.
4. Thus, the genes for the most favorable characteristics are passed to future generations.
5. The "naturally selected" offspring will lead to new species by mutations and genetic changes.

Darwin was not the first to theorize about the nature of animals and how humans and animals exhibit some similar characteristics of structure, for example, four limbs, head end, tail end, head with mouth and eyes, similar internal organs, and so forth. Aristotle based his observations of plants and animals on specific anatomical differences and obvious characteristics and from these observations placed groups with common features on ascending steps of his "scala naturae" or "ladder of life" with man being on the top step (*see* Aristotle). Plato's concept of life was that each living organism possessed something that was unique to that type of organism. To Plato these "essences," although abstract, were what made all the differences in the types of organisms that were separate from other types of living things. This concept did not leave much room for the development of slow variations (evolution) or rapid changes (catastrophism) in organisms. During the Dark and Middle Ages the Roman Catholic Church based differences in living organisms on a hierarchy of God's creation where humans were below the angels while other creatures were below humans. Some adherents of religion believed this then, as well as today, as a part of God's grand design. Carolus Linneaus designed a classification or taxonomic system of organisms that grouped them by major characteristics into categories. In a sense, this was an elaboration of Aristotle's "ladder of life." Linnaeus used scientific names in a hierarchical system ranging from most general to the specific as phylum, class, order, family, genus, and species. Things began to change at the end of the Renaissance and the beginning of the period of Enlightenment with the study of Earth's geology. The age of Earth was greatly extended from the Biblical estimation of a few thousand years to a more realistic age of several billion years as determined by scientific studies. This extended period provided adequate time for slow variations within species to appear and even new species to emerge. Nicolaus Steno was the first person to realize that in a sequence of sedimentary rocks the oldest strata lay at the bottom and the younger strata are at the top. Scientists soon realized that fossils found in various strata of Earth's crust lived at different periods and that changes occurred over many years, as indicated by the depth of the layers of rock in the earth.

Darwin received a letter from Alfred Russel Wallace that outlined the same theory of natural selection as Darwin was developing. Because Darwin formulated the theory first, he is credited, along with Wallace, with the concepts of organic evolution. Darwin's book *On the Origin of Species by Means of Natural Selection* (1859) caused much debate in the general public and among religious groups. Although Darwin didn't emphasize the evolution of humans from lower forms of animals, it was the natural conclusion to be drawn from the theory. Because the concept of **genetics** and heredity was unknown to Darwin, he relied on the mistaken Lamarckian idea of inheriting acquired characteristics to explain the transfer of characteristics from parents to offspring. Many years before Darwin's time, Gregor Mendel had proposed the general concept of inherited characteristics. It was only after Darwin's death that Mendel's work was rediscovered and applied to organic evolution. Since then, the role of random genetic mutations (and RNA and DNA molecules) is better understood as to how these inheritable changes can equip living organisms to survive in their environments and thus produce more offspring with similar traits.

Even today there are substantial numbers of people who believe the development of species required some type of "intelligent design" by a supernatural designer because they believe that organic life is just too complex to have been formed and altered by the processes of evolution. To help counteract this antiscientific screed the National Academies of Science published *In Science and Creationism: A View from the National Academy of Science* in 1999 that outlined the following evidences for evolution:

1. *Paleontology*: Ancient bones and other fossils provide clues about what organisms of the past looked like and when they lived.
2. *Anatomy*: The structures of different organisms are based on similar plans, with differences reflecting their requirements for survival in different surroundings.
3. *Biogeography*: The myriad kinds of organisms on Earth and their many specialized niches are best explained by natural selection for useful adaptations.
4. *Embryology*: The embryos of very different animals, such as chickens and humans, look remarkably similar at certain stages in their development. Common ancestry seems to explain the similarities best.
5. *Molecular biology*: DNA is very similar in all organisms, especially in those that are closely related. The same twenty amino acids are used in building all kinds of

Figure D5. A map of Darwin's trip on the *H.M.S. Beagle.*

Charles Darwin, familiar with the principles of population proposed by the English demographer and political economist Thomas Malthus, also recognized that these theories are applicable to humans. Darwin was also knowledgeable of the book *Principles of Geology* by the English geologist Sir Charles Lyell who questioned the then-held concept of ''catastrophic evolution'' that proposed that animal species were created separately and were unchangeable forever. Lyell, as a geologist, was aware that Earth's surface changes constantly as natural forces act on it over long periods of time. Darwin's observation on the voyage aboard the *H.M S. Beagle* seemed to agree with Lyell's idea of ''general uniformatarianism'' where present geological events occur similar to past geological events.

Darwin based his new theory of natural selection on his years of observing the lands he visited and the great variations in geology. He associated this information with the great variety of plants and animals he collected and studied on this voyage. He spent five years, much longer than he anticipated, aboard the *Beagle* as he visited islands and coastal areas of South America. He recognized that the environment could affect the selection of individuals within species and could, over long periods of time, alter these same species, including the appearance of new characteristics and species. Darwin used the term ''descent with modifications'' instead of ''biological evolution'' as we think of it today.

life. Some stretches of DNA represent "excess baggage" carried from ancestors but not used in their descendants.

See also Dawkins; Dobzhansky; Elton; Lamarck; Linneaus; Lysenko; Mendel; Steno; Wallace

DAVISSON'S THEORY OF DIFFRACTION OF ELECTRONS: Physics: *Clinton Joseph Davis*son (1881–1958), United States. Davisson shared the 1937 Nobel Prize for Physics with George P. Thomson.

The angle of reflection of electrons from the surface of a crystal surface depends on the crystal's orientation. (In other words, electrons can be diffracted similar to light waves, i.e., photons.)

Clinton Davisson was born in 1881 in Bloomington, Illinois. In 1902 after graduating from the local high school he enrolled at the University of Chicago. Due to the lack of funds he left the university and sought employment in various jobs until returning to Chicago to receive a BS degree in 1908. He entered graduate school at Princeton University and received his PhD in 1911. He sought enlistment in the U.S. Army in 1917 but was turned down. Soon after that he sought employment at the Western Electric Company, that later became Bell Telephone Labs. He spent the remainder of his career at Bell Labs experimenting with electron diffraction and how to apply his theories of the electron to engineering. After retiring in 1946 he spent a few years as visiting professor of physics at the University of Virginia in Charlottesville, Virginia. In addition to his Nobel Prize, he received the following awards in his lifetime including The Comstock Prize by the National Academy of Sciences, the Elliott Cresson Medal awarded by The Franklin Institute, as well as medals from the London Royal Society, and the University of Chicago Alumni. Davisson also held honorary doctorates from several universities.

This theory was confirmed in 1927 by an experiment called the Davisson–Germer Experiment. Davisson in cooperation with the American physicist Lester Germer (1896–1971), who was a colleague at Bell Labs, built a vacuum box containing a heated filament that produced electrons that were accelerated at high voltage. They focused this electron light beam of known energy (momentum) at an angle to the surface of polished nickel metal. They were then able to determine that the reflected (or diffracted) angle of the electron beam from the nickel surface was the same as an electron's wavelength. This experiment was somewhat accidental and due, in part, to a patent suit involving Western Electric Company Laboratory, the former name of Bell Telephone Laboratory, and Irving Langmuir of the General Electric Company. An accident in Davisson's lab in 1925 resulted in the serendipitous result of light particles scattering at a particular angle. Davisson and Germer then enacted the famous 1927 experiment to confirm Davisson's earlier discovery that was used to confirm Louis de Broglie's 1924 experiment on wave/particle duality.

The wave characteristics of an electron is also known as the de Broglie wave and is expressed by the equation $\lambda = \hbar/p$ where λ is the electron's wavelength, $\hbar$ is Planck's constant, and p is the electron's momentum (energy). Later Albert Einstein confirmed the particle nature of light waves (photons). The particle–wave duality of electrons became a debate of exactly what is the nature of electromagnetism and the underlying ideas of quantum mechanics. Davisson, de Broglie, and others believed in the concept of determinism in physics and that there was and is still more to be learned about the fundamental nature of matter. Later, Einstein confirmed the particle nature of light waves (photons). The particle–wave duality of electrons became a debate of concerning the exact nature of electromagnetism and the underlying ideas of quantum mechanics.

DAVY'S CONCEPT THAT ELECTRIC CURRENT CAN BE USED TO SEPARATE ELEMENTS: Chemistry: *Sir Humphry Davy* (1778–1829), England.

The process of electrolysis can be used to separate alkaline earth metals from their mineral ores.

Humphry Davy was familiar with the experiments that produced electricity by electrochemical experiments conducted in the past, especially Galvani's frog tissue, the Voltaic pile, and Daniell's gravity cell. It was well known in the early 1800s that water could be separated into hydrogen and oxygen gases by using Volta's pile, and that some solutions of salts could be decomposed in a similar manner. Davy's concept was based on the idea that electrical forces held together the different elements found in chemical compounds. In 1806 Davy gave a lecture on this topic titled "On Some Chemical Agencies of Electricity." Using this concept he theorized that passing a current through molten oxides of metals would decompose these substances. His first success was when he passed a current through a mixture of molten potash and sodium chloride (salt). When he placed several small pieces of metallic potassium metal in water, a gas was produced. The gas from these particles ignited with a bluish flame as the potassium earth metal reacted with the water. The gas was hydrogen that was ignited by the heat of the reaction of the potassium with the water ($H_2O + 2K \rightarrow K_2O + H_2\uparrow$). From there Davy went on to discover magnesium, strontium, and boron.

Several chemists of the day considered oxygen to be a major ingredient of all acids. Davy experimented with what was known as "oxymuriatic acid" which was thought to be composed of oxygen. Davy created a reaction of chlorine with ammonia that produced only muriatic acid (hydrochloric acid) and nitrogen gas, but not oxygen ($3Cl_2 + 2NH_3 \rightarrow 6HCl + N_2$). Later, he also proved that muriatic acid (also known as marine acid) was only composed of the elements chlorine and hydrogen, with no oxygen.

Davy taught himself chemistry and became an expert in applying the scientific method when performing many experiments. He was considered an excellent "qualitative" chemist but lacked the training as a "quantitative" chemist, meaning he was an excellent experimenter with some good ideas, but a bit unreliable with his measurements. He experimented with oxides of nitrogen as well as other gases. His data on the oxides of nitrogen (NO_2; NO, and N_2O) was used to confirm John Dalton's atomic theory that atoms combine in whole numbers when forming compound molecules. He was famous for his lectures and demonstrations that became popular social events. The demonstrations where he and other chemists demonstrated the effects of nitrous oxide on members of the audience became very popular. Davy himself had inhaled nitrous oxide gas (known as laughing gas) and became intoxicated. Davy became temporarily blinded when one of his experiments exploded. He hired an assistant, Michael Faraday, who had attended most of Davy's lecturers and showed an interest in Davy's research. As Davy's health failed from inhaling the gases he produced, Faraday became a valued assistant and friend. Faraday went on to become a successful experimenter in his own right. Davy was responsible for developing many scientific ideas and devices. One of his major accomplishments was the invention of the miners' safety lamp that could be used in mines without causing explosions by igniting mixtures of coal gas and air. He demonstrated that when two pieces of ice or any substance with a low melting point were rubbed together, they would melt without the addition of heat. This led to a better understanding of heat that eventually became known as the atomic kinetic theory rather than the then accepted "caloric theory" of heat. He also developed a method for using a gel of silver nitrate on a sheet of glass to produce a picture as a negative image. This was before tintypes were popular (*see* Daguerre). Davy developed a new chemistry approach to the study and practice of agriculture that was based on experimentation. He applied his knowledge of chemistry to develop an improved method for tanning leather and used his knowledge of electrochemistry to protect copper-bottomed ships by placing zinc plates on the copper. Toward the end of his life Davy became jealous of Faraday and twice opposed his membership in the Royal Society. However, in 1824 Faraday was finally made a Fellow of the Royal Society. Davy, in poor health from breathing his experimental gases, retired to Rome. He died of a heart attack in Geneva, Switzerland, in 1829.

DAWKINS' THEORY OF EVOLUTION: Biology: *Richard Dawkins* (1941–), England.

Hierarchical reductionalism occurs in genes and the DNA molecules, which are the basic units of natural selection responsible for the evolution of organisms.

Richard Dawkins applied knowledge of genes and heredity to Darwin's theory of organic evolution. The genetic and molecular materials in the DNA base pairs of **nucleotides** are the fundamental units of natural selection. Dawkins refers to them as the "replicators," while the entire organism is the "vehicle" containing the genetic DNA "replicators." In his book *The Selfish Gene* (1976), Dawkins described his theory by stating that only the genes and molecules of DNA are important for natural selection to maintain the species. The individual organism is just a means of maintaining and replicating the DNA. How successful the species is depends on how well the replicating factors build the vehicles (bodies of plants and animals) that "store" and "reproduce" the DNA genetic material through natural selection. Dawkins expands his theory to include a form of sociobiology or "social Darwinism" he refers to as "kin selection" rather than individual selection as being responsible for the behavior that results in passing on the organisms' genes. He claims that kin selection explains many social and altruistic behaviors of some organisms. To expand and define this concept, he coined the term "**meme**" as the unit for cultural or social inheritance, with memes responsible for the evolution of ideas through natural (human) selection. Memes are also regulated by evolutionary processes in the sense that families, tribes, and social, and cultural groups create human environments that evolve with their culture. Memes, as units of cultural inheritance, evolve just as genetic material, through the process of natural selection. Dawkins also contends that current living organisms, including humans, are random "accidents." Dawkins' basic idea of evolution states that by following a few rules of physics and starting at very simple points (energy, **amino acids**, self-replicating organic molecules, etc.), life can evolve. Thus, under natural conditions, a variety of complex organisms and their cultures can evolve, but not necessarily in any one given direction. Dawkins believes no supreme being is required to start or direct the process.

There has been, and still is, much controversy over Dawkins' concept of hierarchical reductionism as applied to evolution. It is usually used by physicists to explain the structure and behavior of atoms in terms of elementary particles, molecules in terms of atoms, and so on, up the ladder to the structure and behavior of living cells as related to their component atoms and molecules. Sociobiology continues the hierarchical model to include not only the structure but also the behavior of humans and what species might follow humans based on the most elementary of quanta of energy and matter. Note that it is system-involving feedback. In other words, hierarchical reductionism also states that small, individual parts made up of differentiated cells and tissues evolve into an entire organism whose structure as well as behavior (culture, society, psychology) is expressed in a hierarchical sense in terms of the most basic particles such as **quarks** and **leptons**, **superstrings**, **membranes**, and finally energy.

In addition to *The Selfish Gene* (1976) Dawkins has published *The Extended Phenotype* (1982), *The Blind Watchmaker* (1986), *River out of Eden* (1995), and a number of scientific papers. More recently he wrote *The God Delusion* (2006). He is the professor for the understanding of science at Oxford University.

See also Darwin; De Vries; Dobzhansky; Wallace

DE BEER'S GERM-LAYER THEORY: Biology (zoology): *Sir Gavin Rylands De Beer* (1899–1972), England.

> *The development of animal cartilage and bone cells originates in the ectoderm of animal embryos.*

Up to this time, the accepted germ-layer theory stated that bone and cartilage cells were formed in the mesoderm (the middle layer of tissue) rather than the ectoderm, the outer layer of embryonic tissue. De Beer's theory contributed to the knowledge of how the vertebrae are developed in reptiles, birds, and mammals. Recent research used genetically engineered cells implanted in chicken embryos to produce a protein that determines the bone structure of a bird's wing. This led to the knowledge that similar genes shape the human arm, as well as the general skeletal structure and organs of all animals, including humans. De Beer also demolished Haeckel's law of recapitulation (also known as the biogenic law), which states that ontogeny (embryo development) recapitulates the phylogeny (evolutionary history) for each individual. In other words, each embryo undergoes all the stages of development that resemble all the stages of ancestral evolution of that organism's species. The law of recapitulation is an oversimplification of embryology as well as evolution and is no longer considered viable. Instead, De Beer framed his argument on the concept of *pedomorphosis*, which is the evolutionary retention of some youthful characteristics by adults. He also proposed the concept of *gerontomorphosis* where juvenile tissues are somewhat undifferentiated and are able to undergo further evolution, while more highly specialized tissues are not as likely to change through evolution. De Beer also came up with an explanation called *clandestine evolution* based on evidence of sudden evolutionary changes in fossil records, rather than gradual transformation as proposed in Darwin's concept of evolution.

De Beer used his study of the fossils of *Archaeopteryx,* the earliest-known prehistoric bird, to account for the obvious gaps in evolutionary changes in animals. According to De Beer, these "gaps" are due to the nonsurvival soft tissues in the fossils of animals. He referred to this as "piecemeal evolution changes" that explained the similarities between structures such as teeth, and feathers for reptiles and birds. He expressed his ideas by the statement that *each ontogeny is a fresh creation to which the ancestors contribute only the internal factors by means of heredity*.

Between 1924 and 1972 De Beer authored 17 books ranging from growth, embryology, zoology, evolution and Darwin, and unsolved problems in homology. After his retirement, De Beer moved to Switzerland where he published his work on Darwin and completed his massive *Atlas of Evolution*.

See also Darwin; Haeckel; Linnaeus; Wallace

DE BROGLIE'S WAVE THEORY OF MATTER: Physics: *Prince Louis Victor Pierre Raymond de Broglie* (1892–1987), France. De Broglie was awarded the 1929 Nobel Prize for Physics for his discovery that electrons exhibit wave characteristics.

> *A particle of matter with momentum (mass $\times$ velocity) behaves like a wave when the wavelength is expressed as $\lambda = \hbar/p$. (λ = wavelength, $\hbar$ = Planck's constant, and p is the particle's momentum.)*

In the *macro* world (large masses), when a body, such as an automobile is moving (the *p* in the formula), its energy or momentum is very great. Therefore, because Planck's constant ($\hbar$) is a very small number, and thus the value of the wavelength (λ) is so small, the wavelength behavior of the automobile cannot be discerned. However, in the nano or submicro world (very small particles of mass), such as electrons and protons, the particle will have little momentum (due to miniscule mass but great velocities), and therefore the particle's wavelength is easily detected and measured.

The effects of interference demonstrate the evidence for this theory (*see* Figure Y1 under Young). If a beam of submicroscopic particles is divided into two parts as it passes through two slits in a screen (diffraction), the small particles with minimal mass will arrive at different points on a target screen. The results can be measured, and the results are the same as they are for a similar experiment done with light photons and waves. The characteristics of constructive interference resulting from the split screen for the particles of matter are the same as the characteristics of wave motion. Two other scientists experimentally determined the wave-like behavior of minute particles. George Thomson and Clinton J. Davisson independently discovered the same principle. De Broglie's wave theory of matter supported and helped Erwin Schrödinger explain the theories of relativity, as well as wave and quantum mechanics.

See also Bohr; Born; Davisson; Einstein; Heisenberg; Schrödinger; Young

DEBYE–HÜCKEL THEORY OF ELECTROLYTES: Chemistry: *Peter Joseph William Debye* (1884–1966), Netherlands/United States, and *Erich Armand Arthur Joseph Hückel* (1896–1980), Germany.

> *In concentrated solutions, as well as dilute solutions, ions of one charge will attract other ions of opposite charge.*

Up to this time, the Arrhenius theory of ionic conductivity was correct only for very dilute solutions (*see* Figure A7 under Arrhenius). This theory, formulated in 1923, initiated the use of **electrolysis** for the separation of ions in very concentrated solutions (e.g., brine), for the extraction of sodium and chlorine, and led to the industrial production of gases, such as bromine, fluorine, and chlorine, as well as the extraction of some metals from their ores. Using X-ray diffraction, Debye and his assistant, Erich Hückel, determined the degree of the polarity of covalent bonds and the spatial structures of molecules, which disproved earlier theories of conductivity in strong electrolytes.

Peter Debye was an electrical engineer who received a PhD in 1910 in physics at Zurich University. This was followed by a series of administrative positions in universities and institutes in Germany and Switzerland. He moved to the United States in 1940 where he became a professor of chemistry at Cornell University in New York State. He became an American citizen in 1946. Throughout his career he was essentially a theoretician who considered varied problems related to the structure of matter, mainly how to apply experimental physics to solving problems of molecular structure. His early work involved the electron diffraction by gases, the formation of X-ray diffraction patterns from molecular substances, how to determine the degree of polarity and angles of covalent bonds in molecules, and how to use X-ray spectra to determine the spatial configuration of molecules. But his most famous work was the 1923 Debye-Hückel theory of electrolysis.

See also Arrhenius; Hückel

DEHMELT'S ELECTRON TRAP: Physics: *Hans George Dehmelt* (1922–), United States. Dehmelt shared the 1989 Nobel Prize for Physics with Wolfgang Paul and Norman Foster Ramsey.

> *By isolating an electron in an electromagnetic field, it is possible to suspend it, thus providing a means of continuously and accurately measuring its characteristics.*

Hans Dehmelt constructed what was then known as the *penning trap*, a combination of a strong magnetic field combined with an electric field. Both fields are contained in a vacuum inside a closed unit containing two negatively charged electrodes and one positive electrode that are used to isolate and suspend a single electron so it could be studied. He accomplished this by reducing the kinetic energy (motion) of the electron by cooling it, enabling him to measure the suspended single electron accurately. Dehmelt and his colleagues were also the first to isolate and detect individual protons, antiprotons, positrons (positive electrons), and ions of some metals. The penning trap could be used to analyze particles that had either negative or positive charges. When light was shone on a suspended single metal ion, it could be seen without the aid of instruments and appeared as a very small, bright, star-like light.

See also Ernst; Franck; Heisenberg; Hertz; Pauli; Ramsey; Rutherford; Stern; Thomson

Dehmelt and his assistants were the first to view what is known as the *quantum leap*, a very, very small ''bit'' of energy. This occurred when a single electron of a barium atom ''absorbed'' extra energy and was forced to a higher energy orbit. When the energized electron ''jumped'' back to its normal lower energy state (orbit), it emitted the tiny bit of energy that it had gained when forced to the higher energy orbit. This jump of the electron to a lower energy state is evident by the release of a quantum bit of energy that is detected as a photon (a particle of light). The media and others often refer incorrectly to a large increase in something as a ''quantum leap,'' meaning something big. A quantum leap is really a very, very small amount of energy that becomes visible when an energized electron jumps to a lower energy orbit (*see* Figure D6). Dehmelt's work led to confirmation of quantum mechanics theory and a better understanding of the physics of subatomic particles.

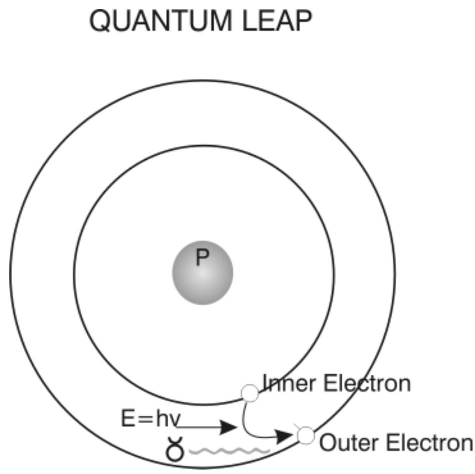


Figure D6. The quantum leap is based on Niels Bohr's idea of electrons being similar to planets orbiting the sun and with specific energy levels. The ''leap'' occurs when a electron, which cannot revolve around the nucleus in just any orbit (energy level), jumps from an inner orbit (higher energy level) to an outer, lower-energy-level-orbit, emitting a photon (a tiny packet/quanta of light). The energy level of the photon is equal to the difference in the energy levels of the two orbits of the electron, which is expressed as Planck's hypothesis $E = \hbar v$ where $\hbar$ is Planck's constant and v is the angular momentum of the electron.

DELBRÜCK'S AND LURIA'S PHAGE THEORY: Molecular Biology: *Max Delbrück* (1906–1981) and *Salvador Edward Luria* (1912–1991). Delbrück was born in Germany, Luria in Italy, but both moved to the United States. Along with Alfred Hershey (1908–1997) from the United States, they shared the 1969 Nobel Prize for Physiology or Medicine.

The phage theory states: *Bacteria develop resistance to phages by spontaneously mutating.*

Phage, a Greek word meaning "devour" or "eat," is the simplest genetic system known. Phages are simple viruses composed of plain strands of nucleic acid with a more complex "head" that contains DNA material. The phage that infects bacteria is referred to as *bacteriophage*.

Delbrück's and Luria's research sought to ascertain how phage could multiply so rapidly in bacteria—up to one hundred phage particles are produced in just a few minutes. Delbrück did the mathematical and statistical work on the problem, while Luria conducted the experiments. Along with Alfred Hershey, they investigated and determined the genome of phage virus. The **genome** is *the entire* DNA, including the DNA in the genes that are contained in the structure of an organism. Delbrück and Luria demonstrated that the phage virus inserts itself into the host bacteria and replaces the bacteria's DNA with the phage's own DNA, in essence cloning itself and resulting in mutation of the bacteria. Delbrück and Luria published "Mutations of Bacteria from Virus Sensitivity to Virus Resistance" in 1943 in which they speculated that bacteria could acquire resistance to lethal phages. They realized that the growth of bacteria would be different for each kind of bacteria within a colony of bacteria because in such numbers a resistant strain would be found. This led to their discovery that bacteria underwent mutations, just like other organisms. They also determined some genetically mutated bacteria develop a resistance to the destructive bacteriophage. The three Nobel Prize winners are credited with founding the field of molecular biology.

See also D'Herelle; Northrop

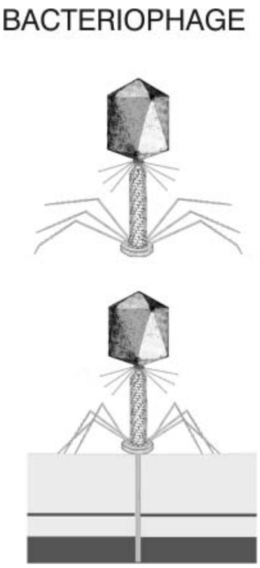


Figure D7. An artist's conception of a typical T4 bacteriophage virus that infects bacteria cells. It consists of two major parts, nucleic acid (RNA or DNA) in the "head" and a coating (capsid) made of protein to protect the nucleic acid. A specific bacteriophage infects only a limited range of bacteria species.

DEMOCRITUS' ATOMIC THEORY OF MATTER: Chemistry: *Democritus of Abdera* (c. 460–370 BCE), Greece. *see* Atomism theories.

DESCARTES' THEORIES AND PHILOSOPHY: Philosophy: *René du Perron Descartes* (1596–1650), France.

Descartes' theory of light and reflection: *White light is pristine light that can be reflected at an angle equal to the angle at which it strikes a mirrored surface.*

Descartes believed that pristine (white) light produced colored light only when there was a "spinning" sphere of light. He also stated that the angle of incidence is the angle formed between the perpendicular to the surface and the ray of light striking the surface. This was a simple way of explaining the law of reflection because the angle of incidence is equal to the angle of reflection, which was later developed and became known as Snell's law. Descartes' concept of light and matter was more metaphysical than empirical.

Descartes' concept of motion: *The force of motion is the product of mass times velocity.*

Today we refer to his force of motion as *momentum* (mass $\times$ velocity). This concept was accepted by Newton but opposed by Leibniz. Leibniz incorrectly assigned the force of a body as the product of mass times the velocity squared, which later developed into the idea of kinetic energy. This dispute led to conflicts in different schools of philosophy.

Descartes' mathematical concepts: *1) a systematic approach to analytic geometry (combining algebraic and geometric functions); 2) the invention of exponential notation; 3) a rule for determining the positive and negative roots for algebraic equations;* and *4) the development of equations to describe specific curved lines and curved surface area.* All were important to the development of calculus, a branch of mathematics that combines differential and integral functions used to determine the area within a curved surface.

Descartes was the first to relate motion to geometric fields. He saw a curve as being described by a moving point. As the moving point describes the curve, its distance from two fixed axes will vary according to that particular curve. This is known as the Cartesian coordinate system, which lends itself to the study of geometry by algebra as a means of interpreting graphs with the x (horizontal) and y (vertical) coordinates that compare two variables. Graphs have become a major geometric and analytic tool for all sciences. All of these concepts contributed to later developments by other mathematicians.

Descartes' philosophy and system of knowledge: *1) Nothing is true until a foundation (evidence) has been established for believing it to be true. 2) Start with* a priori *assumptions (first principles), proceeding by mathematics to deductions that use physics and mathematics. One cannot have complete knowledge of nature because there is always doubt; one is never certain of the nature of nature. In addition, reason deceives us. Therefore, a person can be certain only of doubting (not knowing for sure).* Note: These philosophical ideas of Descartes are also the basis of the modern scientific approach to research and knowledge.

These philosophical concepts led to his famous phrase, which summed up Descartes' total philosophy as "I think, therefore I am," which he asserted as justification of self and God. Descartes' greatest contributions were in mathematics and philosophy, and he believed there was great unity in the study of these two sciences. His application of algebraic methods to geometry was a major step in the progress of mathematics as well as other sciences.

See also Euclid; Leibniz; Newton

DE VRIES' "PANGENES" THEORY OF EVOLUTION: Biology: *Hugo De Vries* (1848–1935), Netherlands.

> *1) Organisms consist of large groupings of physical characteristics. 2) Each characteristic is attached to particles inside the nuclei of cells. 3) Although invisible, these hypothetical particles were referred to as "**pangenes**" by Darwin, which he theorized as units controlling heredity. De Vries equated them to the concept of chemical atoms. 4) Theoretically, when pangenes combine, they cause the appearance of unique characteristics for each species. 5) The more pronounced a particular character or feature of a species, the greater are the number of pangenes. 6) Pangenes may be dominant or latent (recessive and not visible in the organism). 7) During **meiosis**, pangenes may split, each causing new features or possibly new species. 8) When splitting or "mutating," pangenes are responsible for the formation of new pangenes, which produce new "mutants."*

Hugo De Vries rejected the idea that natural selection over long periods of time could produce new species and/or variations in existing species, as Darwin's theory of evolution proposed. De Vries believed new characteristics or species could come about only by genetic changes (mutations) in cell nuclei or organisms. His theories were not all correct, but they did explain that mutants have extra sets of **chromosomes** in their nuclei (triploids and tetraploids). Although the term "pangenes" is no longer accurate or used, De Vries' explanations give a reasonable account of how variations, later determined to be due to genetic mutations and natural selection, occur in the evolution of species.

See also Darwin; Dawkins; Dobzhansky; Lamarck; Mendel

DEWAR'S CONCEPT OF LIQUEFYING GASES: Physics and Chemistry: *Sir James Dewar* (1842–1923), England.

> *Increasing the pressure while reducing the temperature of a contained gas, and then rapidly releasing the pressure, will cause the gas to be liquefied.*

James Dewar was a chemist and physicist who worked in several fields but is best known for his work with low-temperature applications. In one sense, Dewar was more of a

James Dewar is known not only for his work on liquefying gases, but also for devising a special container for storing and transporting liquid gases. This container is known as the ''Dewar flask'' and is constructed as a metal or glass bottle-within-a-bottle that has a silver coating on the inside and outside.

The thin-walled flask is a double-layered jar with one container inside the other and a dead air space between them, usually with most of the air removed so that there is a vacuum seal between the two containers. The only opening is at the neck of the bottle with a plug device designed to release the pressure as the liquid gas slowly boils forming a gas under pressure. The reflective surface, particularly on the inside of the inner container is important to prevent heat radiation. When the Dewar flask is to be used to transport liquefied gases, the outside container is usually made of metal with a reflective surface.

The more common form of the Dewar flask is known as a Thermos bottle used to keep hot liquids hot and cold liquids cold. The name ''Thermos'' is a trademark for three independent companies, one in the United States, one in England, and one in Canada. German glassblowers manufactured small Dewar flasks and held a contest to name the device. The name ''Thermos'' won. It is derived from the Greek word *therme*, meaning ''heat.'' Today, it is one of the most widely known and popular devices used from the Arctic and Antarctic regions to the equator.

scientific inventor who discovered some important and practical processes using known physical and chemical phenomena.

James Dewar was born in Scotland and educated at the University of Edinburgh in Scotland, where in 1869 he taught chemistry at that institution's Royal Veterinary College. He later became professor of experimental natural philosophy at the University of Cambridge, England, in 1875, and in 1877 he became a professor of chemistry at the Royal Institution in London where he did most of his experimental work. He used a known apparatus to successfully liquefy oxygen in commercial amounts but had no way to store oxygen in liquid form because it would quickly "boil" into gaseous oxygen. This problem led to his invention of the "Dewar flask" which is a specialized bottle to store liquefied gases (*see* the sidebar for details).

Some of Dewar's other accomplishments are:

1. Dewar is best known for his scientific work of the nature of matter at near absolute zero degrees temperature (0 kelvin [K] or −273°C). He was successful in lowering temperatures to 14 kelvin. It was some years later when helium gas was liquefied at 2.2 K that a lower temperature was achieved.
2. He developed the chemical formula for benzene (C_6H_6) through his long-time use of the spectroscope (*see* Kekule).
3. In 1889 Dewar in cooperation with the English chemist Sir Frederick Augustus Abel (1827–1902), invented smokeless gunpowder, now known as cordite.
4. He identified the specific heat of hydrogen gas and became the first person to liquefy hydrogen gas in 1898, and to produce solid hydrogen in 1899.
5. In 1905 he perfected a way to cool charcoal that can be used to create a high vacuum in an enclosed environment. This discovery has been useful in the study of atomic physics.

D'HERELLE'S BACTERIOLYTIC THEORY: Biology: *Felix d'Herelle* (1873–1949), Canada and France.

When bacteria are infected by viruses and the resulting fluids are filtered, the filtrate contains no live bacteria, but this filtered fluid can still infect bacteria. Because the *infection agents are smaller than bacteria, they are thus "filterable viruses" that can still act as parasites on live bacteria.*

After attending school in Paris, Felix d'Herelle returned to Canada, his birthplace, where he enrolled and graduated from the medical school of the University of Montreal. He started his work in bacteriology in Mexico in 1907 but returned to France in 1911 to accept a position at the Pasteur Institute. From there he moved to the Netherlands to the University of Leiden as a temporary professor, followed by a stint as a bacteriologist in Egypt, and ending up as the chairman of the Department of Bacteriology at Yale University where he remained until 1933.

Throughout his career d'Herelle traveled extensively to Argentina, Guatemala, Indochina, India, and in 1934 to Soviet Georgia. He wrote *The Bacteriophage and Phenomenon of Recovery* while working at the Tbilisi Institute. He dedicated his book to Joseph Stalin. However, due to Stalin's tyrannical rule, d'Herelle was forced to flee the country just as World War II began. He and his family returned to Paris. He was nominated for the Nobel Prize a total of 30 times but never won.

In the early 1900s while working in the Yucatan in Mexico Felix d'Herelle discovered the bacteriophage, which is a type of virus that infects and destroys bacteria (*Virus* is the Latin word for "poison." *See* Figure D7 under Delbrück). After filtering this virus from a mixture of infected bacteria, he discovered that the filtrate could still infect and kill bacteria. He referred to this filterable virus as a "bacteriolytic agent." He continued his work with cultures of dysentery bacilli and found that a filterable parasitic virus also kills these types of bacilli. In 1921 he wrote a monograph "The Bacteriophage, Its Role in Immunity" where he advocated using bacteriophages to treat diseases such as cholera and bubonic plague. Although he claimed some successes in India and Egypt, others using his techniques could not achieve the same level of successful treatments. His experiments and conclusions were not well accepted by those investigating bacterial-viral problems because it was not understood how, once filtered, the virus could still infect bacteria. The term "bacteriophages" and the importance of the filterable viruses in the field of bacteriology later became significant under Delbrück's phage group of researchers.

See also Delbrück; Northrop; Pasteur

DICKE'S THEORY OF THE BIG BANG: Physics: *Robert Henry Dicke* (1916–1997), United States.

The universe started about eighteen billion years ago (Note: the current estimate is thirteen to fifteen billion years as the age of the universe) as a tiny point of energy (singularity) "exploding" in an ever-increasing three-dimensional spread of energy at extremely high temperatures that soon formed elementary matter and radiation.

The big bang theory proposes that the formation of the universe originated with an infinitely dense pinpoint of compressed energy that, at the first fraction of a second of expansion, formed hydrogen and helium and, later, other matter which, under the influence of gravity, became stars and the planets and other objects found in the universe. This "explosion" was the source of all the energy and mass in the universe and was forceful enough to overcome the gravity of the expanding particles that are still expanding after billions of years.

The big bang theory is explained by considering a number of related physical phenomena:

1. A cataclysmic explosion occurred thirteen to sixteen billion years ago.
2. Within a few seconds the temperature reached about 10 billion °C.
3. This high temperature caused intense radiation to spread outward in all directions.
4. Soon after the initial explosion, particles of elementary matter were formed and radiated outward.
5. As the explosion expanded, it lost energy through both heat and radiation.
6. **Cosmology** confirms that this expansion is still taking place, and possibly accelerating.
7. Although it took place billions of years ago, remnants of this radiation should still be detectable.
8. If such residual radiation exists today, it should be detectable as "black body" radiation—radiation, such as X-rays from deep space, emitted from a black body at a fixed temperature.

These eight phenomena provide the basis for the origin of the big bang as a condensed, very small, extremely hot mass of energy. Several different wavelengths of radiation, in addition to visible light, have been detected. For example, radio waves, X-rays, and microwaves have been detected as originating from deep space and are used to further our knowledge of the cosmos and support of the big bang theory.

Calculations determined that the residual temperature from the big bang in the universe is about 3 kelvin (−270°C), and such radiation was later detected as background microwaves of about 7 cm. These factors led cosmologists to conclude the big bang theory is correct. The question remaining is: What was there before the big bang, and where did it all come from? This is more of a metaphysical question than a part of the theory that assumes infinity in time as well as space in both directions—before and after the event—just as it is possible to calculate infinity as negative and positive numbers.

See also Gamow; Hoyle; Weinberg

DIESEL'S CONCEPT OF AN INTERNAL COMBUSTION ENGINE: Physics (Engineering): *Rudolf Christian Carl Diesel* (1858–1913), Germany.

> *By using the compressed heat inside an engine's cylinder to ignite the fuel and drive the piston of an engine rather than using an external source of heat as in a steam engine, greater efficiency can be achieved.*

Born in Paris, Rudolf Diesel and his parents, who were Bavarian immigrants, relocated to London during the Franco-Prussian war of 1870. Soon after, he moved back to Germany where he received a scholarship to the Munich Institute of Technology. Upon graduation, he worked in Switzerland and Paris as a thermal and refrigeration engineer. Diesel was not only an engineer who understood the theory of thermodynamics but was also a linguist who spoke three languages. He was also interested in the technology of the engine. This interest was partially responsible for his work to devise a more efficient source of power to reduce the size of engines and the cost of fuels, thus enabling the smaller independent craftsman to compete with larger corporations. After thirteen years of working on a design for a compression engine, he developed a model that consisted of a 10-foot-long single cylinder that had a rotating flywheel at one end. This was the first working model of a diesel compression engine. After receiving a patent in 1893 for his engine, he continued to make improvements to the engine and spent much of his time attempting to produce it commercially. It was known as the *diesel cycle compression engine* that could use almost any kind of combustible liquid as fuel, even powdered coal dust. In 1900 he demonstrated his engine at the World's Fair using peanut oil for fuel.

By the end of the nineteenth century Rudolf Diesel was a multimillionaire from selling franchises for the production and sales of his engine. It became widely used in all kinds of industries and production plants. As the diesel engine starts to run, it compresses the incoming air and atomizes fuel, raising the temperature in the cylinder to the point where the combustible mixture explodes, thus rapidly and forcibly expanding the hot gas driving the piston outward to suck in a new mixture of air and fuel. This is an excellent example of the *combined gas law* as well as the *law of thermodynamics*. There were two problems with the early diesel engine's use in automobiles. First was the need for a governor to control the speed of the engine's cycles of intake-compression-combustion-expansion-exhaust. The other factor was that most diesel fuels thicken when cold, and this higher viscosity does not enable fuel to flow freely to the engine. Heating the fuel tanks, lines, cylinder blocks, or reformatting the fuels to maintain fluidity at low temperatures has solved this problem. Many users of large diesel construction equipment in the Arctic allow the diesel engines to run, sometimes continuously, between periods of use.

The size and weight of the modern diesel engine has been reduced as the efficiency has been increased to about 80% (whereas the steam engine is only about 10% efficient). There are basically two kinds of diesel engines: the two-stroke and the four-stroke varieties. Most engines are of the four-stroke, six-cylinder-in-line type of engines. There are also four-cylinder and eight-cylinder versions. Greater efficiency is partly achieved due to the high internal temperature of about 700 to 900° Celsius that increases the compression rate to 25:1 (as compared to about a 10:1 ratio for a gasoline engine). Automobiles obtain about 40% more miles per gallon with cars using turbo-diesel engines. Modern diesel engines are also used in trains, buses, heavy equipment, and to power manufacturing industries as well as in automobiles and trucks. New fuel mixtures and fuel injection systems are being developed to help reduce the pollution created by the spark-ignited and pressure/heat-ignited fuels in internal combustion engines.

Later in life Rudolf Diesel experienced financial and severe health problems and suffered from headaches and depression. In 1913 while on the London to Antwerp mail ferry, and after finishing a pleasant meal with friends, he was found missing. Later his body was spotted in the English Channel by another ship but left at sea.

See also Boyle; Carnot; Calvin; Clausius; Ideal Gas Law; Maxwell

DIRAC'S RELATIVISTIC THEORIES: Physics: *Paul Adrien Maurice Dirac* (1902–1984), United States.

Dirac's quantum mechanics: *The physics of electromagnetic radiation and matter should interact on the micro subatomic, very small scale of nature, as well as at the macro, very large scale.*

For almost three centuries, fundamental Newtonian mechanistic laws for classical physics were accepted. These laws explained the stability of atoms and molecules but could not explain the small packets of energy emitted by excited atoms. Albert Einstein developed the special and general theories of relativity, and Edwin Schrödinger developed the wave equation representation of quantum mechanics. Enrico Fermi and Paul Dirac revised and improved the concept for quantum mechanics by incorporating Einstein's calculations for relativity into the equation and making some corrections in the energy levels of "spinning" atoms which resulted in the Fermi–Dirac statistics. This statistic was designed to satisfy the Pauli exclusion principle required to account for the behavior of particles with half-integer spins.

Dirac's theory of negative energy: *Energy exists below the ground state of positive energy.*

To explain his theory, Dirac claimed that areas below ground state (normal positive charge) were already filled with negative energy, and if a light photon tried to enter this area, it would become an observable electron, leaving behind a vacant "hole" representing a potential similar to a positive charge. This theory led to a new understanding about the nature of matter (*see* Dirac's theory of antimatter, which follows). This positive electron was named a positron ($^{+}$e) and was confirmed by Carl Anderson in 1932. It proved to be a new way to look at the universe, which now included antimatter somewhat as a mirror image of matter. If there were exactly the same number of electrons ($^{-}$e) as positrons ($^{+}$e) in the universe, they would collide and destroy each other, resulting in energy with no matter left over. The reason that matter exists in the universe and there are more electrons than positrons is that more electrons (photons/electromagnetic radiation) were produced at the beginning of time. This theory has led to speculation of a "sister" universe based on antimatter (*see also* Anderson).

Dirac's theory of antimatter: *1) Each negatively charged particle (called an electron) has a counterpart. 2) These counter particles are positively charged electrons called positrons. 3) A positron must always occur in conjunction with an electron (but not the other way around). 4) Their collision destroys both.* Thus, *5) electromagnetic waves (radiation) are released, producing more electrons than positrons.*

Dirac's theoretical positron was discovered later by Carl Anderson, who confirmed Dirac's concept of antimatter as applying to all matter. Dirac's theory was an explanation of the dual nature of light where in some instances light behaves as a wave (as indicated by interference and diffraction). In other cases, light resembles particles called **photons**, which are matter similar to electrons with measurable energy, as indicated by their frequency and momentum. Thus, the concept of particle–wave duality is dissimilar to the Newtonian classical mechanics concept of matter.

Dirac's theory of "large number coincidences": *There is a 1 to 10^{40} ratio that is constant in the universe. It is exhibited in various physical phenomena and represents a model of the universe.*

Dirac's mathematics revealed this phenomenon as a relationship between natural physical constants and the quantification or natural properties: 1) The ratio of gravitational attraction and electrostatic attraction between electrons and protons is 10^{40}, 2) Earth's radius is 10^{40} that of the electron's radius, and 3) the square root of the number of particles in the universe is 10^{40}. Dirac considered there was a universal relationship between the ratios of the radii of all objects (e.g., Earth) and all forces (e.g., gravity). He also theorized that as the universe continues to expand with age, this force ratio would not change, even when the distance between objects increases. Rather, the gravitational constant will change; thus the effects of gravity become less as time and space increase (expand). The theory that the gravitational constant is decreasing over time is no longer accepted. On the other hand, to explain the increased rate of expansion of the outermost galaxies in the universe, some cosmologists are suggesting that antigravity might exist at the horizon of the universe. This is not the same as Dirac's theory for the change in the gravitational constant, but both concepts end up with the same conclusion about the expanding universe.

See also Anderson (Carl); Born; Einstein; Fermi

DJERASSI'S THEORY FOR SYNTHETIC ORAL CONTRACEPTION: Chemistry: *Carl Djerassi* (1923–), United States.

Physical methods can be used to determine the structure of organic molecules leading to the translation of this knowledge into the production of synthetic organic steroids related to female sex hormones that control contraception.

Carl Djerassi's father was a physician in Bulgaria and his mother was from Vienna, Austria. He and his parents moved to the United States during World War II in 1939 when Carl was a young teenager. Carl was an exceptional student who graduated from Kenyon College in Ohio with a BS degree at age 18 and received his PhD from the University of Wisconsin by the time he was 22 in 1945. This is the same year he became a U.S. citizen. He recalls that he admired Eleanor Roosevelt, the president's wife, and wrote her a letter stating that he needed a scholarship. Her secretary replied, and he did receive a scholarship. Following graduation he secured a job with CIBA Pharmaceuticals. Then in 1949 he joined Syntex located in Mexico City where he worked with a team that was attempting to identify and extract the steroid cortisone from plants. His team of chemists at Syntex was the first to successfully extract cortisone ($C_{21}H_{28}O_5$) from Mexican yams. Following this success, the team started work on synthesizing the steroid hormone progesterone, known as nature's contraceptive. The team did encounter one problem, however. Hormones produced from the urine, testicles, or ovaries of animals proved to be very expensive. In addition, if taken orally it would lose its effectiveness. In the 1950s Djerassi and his team were successful in the synthetic production of progesterone, which caused a huge drop in cost of the drug. To make this synthetic oral steroid more effective, Djerassi altered the structure of progesterone ($C_{21}H_{39}O_2$) by removing a methyl group (CH_3) from the formula. He also added a bit of the male hormone, testosterone, to the formula to make it more effective as a contraceptive. After some more manipulations of the formula, he received U.S. Department of Agriculture (USDA) approval in 1962 for this synthetic steroid to be used as a contraceptive. From this date the story of how the "pill" has affected lives all over the world by "liberating" women from unexpected and unplanned pregnancies is well known. In 1951 Dr. Djerassi resigned his post at Syntex but continued his career at several universities and was involved with other business interests. He developed a unique form of insect control by applying a biodegradable spray with a hormone that prevents young insects from maturing. Djerassi is a prolific writer and has published many scientific papers, five novels, including *Cantor's Dilemma,* some poetry, short stories, essays, two autobiographies, and a memoir.

DÖBEREINER'S LAW OF TRIADS: Chemistry: *Johann Wolfgang Döbereiner* (1780–1849), Germany.

When considering three elements with similar characteristics and with atomic weights within the same range, the central (middle) element will have an atomic weight that is the average of the total atomic weights of all three elements.

Johann Döbereiner was interested in chemical reactions that involved catalysts, which are chemicals that either speed up or slow down chemical reactions but are not changed or consumed in the reaction. One of his discoveries was that hydrogen gas would ignite spontaneously when passed over powdered platinum. Using this concept, he developed the Döbereiner lamp, which uses metal platinum as the catalyst. (The catalytic converter in the exhaust systems of modern automobiles uses platinum as the catalyst to convert toxic exhaust gases to less harmful compounds.) In his experiments involving catalytic actions, he observed how the atomic weights changed incrementally for elements with similar compositions. This led to his law of triads proposed in 1829. An example is the triad for the nonmetals chlorine (atomic weight 35.5), bromine (atomic weight 80), and iodine (atomic weight 127). When calculating their average atomic weight, $242.5 \div 3 = 80.8$ the approximate atomic weight of bromine, the middle element of the three examples, is attained. A second example is the triad for three metals: calcium, strontium, and barium. This triad's average atomic weight calculates as $265 \div 3 = 88.3$, which is the approximate weight of the middle element, strontium. This relationship of atomic weights to characteristics of similar elements was an important discovery that Dmitri Mendeleev used in designing his Periodic Table of the Chemical Elements (*see* Figure M5 under Mendeleev). Being aware of this phenomenon provided Mendeleev a means to leave vacant spaces in his table that could later be filled. He called yet-to-be-discovered elements *eka elements*. He predicted these eka elements would fit into specific blank spaces where the other two elements in the triad, with known atomic weights, were directly above and below the missing eka element. For example, in Group IVA (14) the yet-to-be-discovered element germanium was named eka-silicon to fill in the vacant space. His eka-predicted elements were very accurate as far as atomic weights were concerned, but they were not always correctly arranged according to specific characteristics of elements in groups. Later, his periodic table was corrected to

Johann Wolfgang Döbereiner's life and education is a good example of bringing yourself up by your "bootstraps." His family was not wealthy, and his father, a coachman, did not contribute to his early education. At fourteen years of age he was apprenticed to several apothecary (pharmacy) businesses where he developed an interest in chemistry which he pursued the rest of his life. Leopold Gmelin (1788–1853), a well-known German chemist, whom Döbereiner met in Strasbourg, encouraged him to continue his study of chemistry. Despite his limited finances, he tried starting several businesses. Although they failed, he was soon given the position as assistant professor of chemistry at the University of Jena, which is now located in Germany. His first success in the field of chemistry was his discovery that when hydrogen gas passes over a spongy-type of platinum, ignition would spontaneously take place. This phenomena of catalytic activity, which he pursued the rest of his life, led to the development of his first successful business venture—the manufacture of the Döbereiner lamp. His interest in chemistry led to his theory of the "law of triads" where the average atomic weight of three related elements will approximate the atomic weight of the middle element of the triad.

represent the elements arranged by their atomic numbers (protons) rather than atomic weights.

See also Dalton; Mendeleev; Newlands

DOBZHANSKY'S THEORY OF GENETIC DIVERSITY: Biology: *Theodosius Dobzhansky* (1900–1975), United States.

> *Populations with a high genetic load of debilitating genes confer an advantage to organisms by providing more versatility within changing environments.*

Theodosius Dobzhansky believed **species** that have a wide variety of genes, even recessive dormant debilitating genes, will be more successful by providing the entire species with greater genetic diversity. This diversity is related to the evolution of race and species and provides more effective adaptation to changing environments. Historically, this meant that those species that survived over long periods of time were the ones with the greatest pool of genes. When these genes no longer provided an advantage in overcoming environmental conditions, natural selection contributed to their extinction over time. Dobzhansky made detailed studies of the fruit fly (*Drosophila*, that has yielded extensive genetic information) and proved his theory that there is considerable genetic variation within a population. Those species that had the greatest genetic variety survived, including lethal genes, which prove to be even more important for survival in changing environments. By all standards, the dinosaurs must have had a very wide and diverse genetic load because there were so many different types of dinosaurs that successfully survived for millions of years. Despite this, they became extinct about sixty-five million years ago. Humans arrived many millions of years after the dinosaurs' extinction. Prehuman types of beings existed about five million years ago, followed by prehistoric humans, and later modern humans (*Homo sapiens sapiens*), who have existed for fewer than one hundred thousand years. Over 98% of all plant and animal species that ever lived are now extinct due to many natural causes. How long present species of plants and animals can or will survive, including modern humans, may depend on the extent of their genetic load, which may mean that humans are at the end of their evolutionary evolvement as a species. Dobzhansky's theories were important in understanding the mathematical relationships of natural selection, as well as Mendelism (also known as Mendelianism).

Born in Russia, Dobzhansky received his BS from Kiev University in 1921 followed by a few years of teaching. He moved to the United States in 1927 on a fellowship at Columbia University in New York City. He soon accepted a position teaching genetics at the California Institute of Technology and became a citizen of the United States in 1937. He wrote several books. The best known is *Genetics and the Origin of Species* in 1937.

See also Darwin; Dawkins; De Vries; Mendel; Wallace

DOMAGK'S CONCEPT OF DYES AS AN ANTIBIOTIC: Chemistry: *Gerhard Domagk* (1895–1964), Germany. Gerhard Domagk received the 1939 Nobel Prize in Physiology or Medicine. Because of World War II, he was unable to receive the award until 1947.

> *By adding sulfonamide compounds to selected dyes, bacterial infections can be controlled.*

For many years physicians sought drugs that could cure patients, particularly those with bacterial infections, such as gonorrhea, meningitis, pneumonia, childbed fever known as puerperal septic (a blood poison), urinary infections, and so forth. Over the centuries alchemists (*see* Paracelsus) treated patients with many toxic drugs including mercury, arsenic, lead, and gold. Their treatments were just as likely to kill the patient as cure their ailments, but some successes occurred. Once bacteria became known as the source of many diseases, the concept of using toxic substances to cure specific diseases became even more urgent. From the late 1930s into the early 1940s the production and use of sulfa drugs increased rapidly. It was used in 1936 to treat President Franklin Roosevelt's son for a streptococcal infection. Sulfa drugs were responsible for saving the lives of many servicemen wounded or suffering from dysentery during the early years of World War II. During the war Churchill was treated with sulfa drugs for pneumonia. By 1942 over ten million pounds of the drug were being produced. Some problems developed with the use of sulfa drugs partially due to their poor solubility, which means crystals of the drug could build up in the kidneys. In addition, some strains of bacteria developed a resistance to sulfa. By the end of World War II a new, more effective antibiotic, penicillin, became available. Today there are numerous varieties of antibiotics, as well as antiviral drugs, available to treat the seemingly growing number of known bacterial and viral diseases.

It is not known who first considered using new types of synthetic dyes to treat diseases, but Domagk based his ideas on research done by Paul Ehrlich and several other scientists. These scientists had some degree of success in using dyes to treat conditions caused by some large organisms, such as protozoa, but were unsuccessful in treating infections caused by small cocci (ball shaped), bacilli (rod shaped), and spirochete (spiral shaped) types of bacteria. After years of research, Paul Ehrlich, a German medical researcher, developed in 1909 an arsenic based compound that was known as "606" because it was the 606th trial for the drug he called *arsphenamine* that proved to be the first effective drug for the treatment of syphilis which is caused by a bacterium known as the spirochete. (Salvarsan, the trade name for arsphenamine, was first marketed in 1910.) There was still a need for an effective drug to use against many types of bacterial infections and diseases. In 1927 the large German chemical company I.G. Farben, for whom Domagk was the director of laboratory research, decided to explore the medical possibilities of the dyestuff it was producing at the time. Because most dyes strongly attach to the protein molecules of cotton and wool fibers (they become "fast"), Domagk theorized that some dyes might also attach themselves to the protein molecules that composed infectious bacteria. Domagk added a chemical called 4-sulfonamide-2′, 4′-diaminoazobenzene hydrochloride to an orange-red dye. He infected rats and rabbits with streptococci bacteria and treated them with the new dye. It did not kill the animals, thus it was nontoxic, while killing the bacteria. For the first time in history, a chemical was found that would combat bacterial infections in humans without poisoning the patient. The drug was first given the name *streptozoan* but was later changed to *prontosil*, the first sulfa drug. Although the drug was not used commercially for several years, it has been reported that Domagk used prontosil to cure his daughter of a streptococcal infection following a pinprick in her arm, saving her arm from almost certain amputation. Sulfonamide compounds soon proved effective in treating streptococcal diseases, such as gonorrhea and epidemic meningitis, as well as staphylococcal infections. They were extremely effective in treating erysipelas (an acute inflammatory disease of the skin and underlying tissue), urinary tract infections, and undulant fever due to bacilli. Sulfa drugs saved many lives during

World War II until about 1944 when penicillin, a superior antibiotic, became available

See also Ehrlich; Fleming (Alexander); Paracelsus

DOPPLER'S PRINCIPLE: Physics: *Christian Johann Doppler* (1803–1853), Austria.

Doppler arrived at his principle as it related to sound. In essence: *the Doppler effect applies to any source of sound (as well any source of electromagnetic frequencies, such as light, radio, and radar frequencies) moving away from or toward an observer that will change in frequency with reference to the observer*. Another way of stating the principle is: *The observed frequency of a wave depends on the velocity of the source relative to the observer, or the observer to the source of the sound or electromagnetic wave*.

Christian Doppler originally applied his effect as it relates to waves of air particles (sound). Later it was experimentally determined to apply as well as to electromagnetic waves such as light. Doppler arrived at his equation about frequency related to velocity of waves based on a unique experiment with sound. He reasoned that when the source of a sound is coming toward an observer, the sound waves that reach the ear are compressed and arrive at shorter intervals and thus at a higher pitch frequency. Although the opposite is also true—as the source of sound waves (or the observer) moves away from each other, the waves that reach the ear are spread out and arrive at longer intervals, therefore, at a lower (pitch) frequency. Doppler placed a group of trumpet players on an open train car and had them play loudly as the train moved away. As the train moved closer, he noted the change in the tone and pitch (frequency of the sound waves) of the trumpet notes. Almost everyone has experienced the Doppler effect. For example, when a train rapidly approaches, its whistle is shrill or high pitched due to the

The Doppler principle provided astronomers with a valuable tool. Armand Fizeau, who determined the speed of light with a unique instrument, also applied the Doppler effect to light waves. This principle when applied to light is sometimes referred to as the *Doppler–Fizeau shift*. The Doppler principle is much more important in the field of astronomy. It was first used to measure the rotation of the sun on its axis. As the sun rotates, the light spectrum on the side of the sun rotating toward Earth is slightly compressed, which makes the light appear bluer. Conversely, the light from the side of the sun rotating away from Earth spreads its spectrum, and thus the sun's light looks more reddish. This principle is also used to measure the motion of stars. If the star appears reddish, it may be receding from us, as its light spectrum spreads out to the red area of the electromagnetic spectrum. This is known as the *redshift* that is due to the shift toward the longer infrared frequency of light waves as stars move away from us. Conversely, if stars are approaching us, they appear bluer due to the compression of the electromagnetic spectrum toward the shorter-frequency blue area of the spectrum. (Basically, most stars are receding from us, but at different rates.) The Doppler principle enables astronomers to measure the distances of stars and galaxies and is used as one of the arguments for an ever-expanding universe.

During World War II, British engineers designed radar (***ra****dio* ***d****etection* ***a****nd* ***r****anging*), which was based on the Doppler effect. It used a specific radio wavelength that could be bounced off a moving object. The returning wave was at a different wavelength from that of the transmitting wavelength. The different frequencies between the sent and the returning wave that was bounced off the target object was used to determine the object's position, altitude, and the rate it was approaching or receding from the radar operator who picked it up. It was also used to develop more accurate bombsights. Since that time, radar has become a valuable scientific tool for navigation, meteorology, and astronomy.

compressed sound waves, which increase the sound waves' frequency. The reverse takes place as the train recedes from the receiver because the sound waves are less close together, and thus at a lower pitch (frequency). Although Doppler predicted that a similar effect would apply to electromagnetic waves, he did not have much success using his principle with light waves. However, using his principle, other scientists demonstrated a color shift of light waves (frequencies) under the same conditions of motion as there was for sound waves.

See also Fitzeau; Olbers; Watson-Watt

DOUGLASS' THEORY OF DENDROCHRONOLOGY: Astronomy: *Andrew Ellicott Douglass* (1867–1962), United States.

Climate and environmental history can be determined by examining the formation of the rings in the cross sections of tree trunks.

Andrew Douglass' first interest was in trying to decipher the eleven-year period of high sunspot activity to the period of low sunspot activity as measured on Earth. (The eleven-year high to the low in a cycle is just one-half of the cycle. A full cycle is from high to high.) The actual complete cycle is twenty-two years from one crest to the next crest in the complete cycle. Douglass initially tried to relate the sunspots' high-to-low part of the cycle to the distinct rings in trees that represent yearly growth. He also hypothesized that there might be a correlation between the rate of growth of other vegetation and Earth's climate and the sunspot cycle. He did not find a correlation between the two but determined the rings were a more interesting area for study as a means of dating the past.

Dendrochronology, Greek for "time-telling by trees," is defined as the study of the rings of growth in mature trees to verify historic climate, weather, temperature change, rainfall, insect populations, diseases, and so on. For instance, it has been determined there were periods of devastation of plant growth due to insect plagues and volcanic eruptions, as well as extended droughts, long before today's pollution problems. The time period during which these events occurred are easily ascertained by carefully examining and counting the rings and their sizes in the cross sections of older trees. Douglass' goal was not only to learn about prehistoric chronology of climate but also to use dendrochronology as a means of predicting future climatic changes, particularly global climate changes. There are some limitations to dendrochronology as a dating tool for historical conditions. Living trees have a definite age; thus you can go back only so far, whereas fossil tree rings can be read back to prehistoric times. Also, using tree rings to correlate global or even hemispheric climate changes has proved to be very inaccurate due to the lack of correlation between the growth rings of trees located in different parts of the same continent and the wide distribution of trees worldwide. More accurate methods for determining past and future climate changes are now available.

THE DRAKE EQUATION: Astronomy: *Frank Donald Drake* (1930–), United States.

The Drake Equation states that: $N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$, where

N is the number of possible civilizations that might be found in the Milky Way galaxy that may, at any time, communicate with us;

R^* is the rate of star creation in our galaxy (estimated by the National Aerospace and Space Administration [NASA] at 6/yr);
f_p is the fraction of those new stars that may have planets (about 0.5);
n_e is the average number of planets (or satellites) that can support life (about 2);
f_l is the number of the above planets that actually develop life (1);
f_i is the fraction of those that will develop intelligent life (0.01);
f_c is the fraction of planets with intelligent life willing to communicate with us (0.01);
L is the expected lifetime of these civilizations (ten thousand years).

The Drake equation is also known at the *Green Bank equation* or the *Sagan equation* (after the popular astrophysicist Carl Sagan who, based on the huge numbers of star systems, assumed that statistically there must be life on planets similar to Earth in some of these systems). This equation is associated with the fields of astrosociobiology, xenobiology, and Search for Extraterrestrial Intelligence (SETI).

Interested in science from an early age, at eight years of age Frank Drake considered the possibility that life existed on other planets. (He never mentioned this idea because of the religious atmosphere at school and home.) After high school, he enrolled at Cornell University and studied astronomy. After a brief "hitch" in the U.S. Navy, he entered graduate school at Harvard University to study radio astronomy. He did his research in this field at the National Radio Astronomy Observatory (NRAO) in Green Bank, West Virginia, and later at the Jet Propulsion Laboratory in California. In 1960 Drake formed the project known as *Ozma,* which was the first radio search for extraterrestrial intelligence. After conducting extensive searches, no evidences of such signals were found. However, Drake refused to give up and was convinced that sooner or later either radio or light contacts were coming to us from outer space.

In 1961, in cooperation with J. Peter Pearman and the Space Science Board of the National Academy of Sciences, they organized a conference at Green Bank that became known as SETI where he first introduced his equation. The *N* in the equation is an example of a large range of outcomes estimated to be between 1 and 1,000,000. The implications of this are that intelligent life on Earth may be a one-time cosmic event or the universe actually holds many such sites of intelligent life. As Carl Sagan stated, there are billions, and billions of suns with planets out there and some of them statistically will support intelligent life.

Frank Drake remains involved in a SETI project known as Project Phoenix. He served as director of the Arecibo Observatory in Puerto Rico, now known as the National Astronomy and Ionosphere Center (NAIC), from the mid-1960s until 1984. From 1984 to 1988 he was professor of astronomy and astrophysics and Dean of Natural Sciences at the University of California, at Santa Cruz, California, where he is currently Professor Emeritus.

DRAPER'S RAY THEORY: Chemistry: *John William Draper* (1811–1882), United States.

> *Electromagnetic rays, absorbed by some chemical substances, can cause chemical changes in that substance. In addition, the rate of chemical change is proportional to the intensity of the radiation.*

The daguerreotype field of photography was based on exposing silver salts to light, which caused the image on the surface of a glass plate coated with silver salts to darken at the points where the greatest amount of light occurred. The problem was that the silver salt continued to darken as it became exposed to more light outside the camera. Draper solved this problem when, after exposure, he dissolved the unexposed silver from the glass plate with a solution of sodium thiosulfate, also known as "hypo." This chemical is still in use today to "fix" the photographic image by dissolving the unexposed silver salts in the emulsion coating the film and paper prints. Draper determined that electromagnetic rays (visible light, X-rays, etc.) cause a chemical reaction when absorbed by some light-sensitive chemicals (e.g., silver nitrate) and that the amount of light and time of exposure are proportional to the chemical changes. Draper was the first scientist to apply the new field of daguerre-type of photography to his work. He was the first to realize that not all electromagnetic rays (including light) were involved in chemical changes, but that only those rays that were absorbed would cause changes. He explained in a scientific paper that the amount of chemical change was related to the intensity of the radiation multiplied by the time of exposure to the radiation. He built cameras out of cigar boxes and perfected the process to the point that he was able to take short exposure photographs of the moon in 1840 and to take the first pictures through a microscope. He was also the first to record the solar spectrum photographically through a **prism** (*see* Figure F8 under Fraunhofer.) In addition, using his sister as a model, he was the first to take a successful, short-exposure portrait that is still in existence. Draper experimented with the size of the **aperture** for the lens, which, if enlarged, would reduce the time of exposure required to expose the image.

See also Daguerre

DULBECCO'S THEORY OF CANCER CELL TRANSFORMATION: Biology: *Renato Dulbecco* (1914–), United States. Renato Dulbecco shared the 1975 Nobel Prize in Physiology or Medicine with Howard Temin and David Baltimore.

> *Normal cells, when mixed with cancer-producing viruses in vitro, will kill some of the cells, while other cells are changed by the virus and will continue to grow and multiply as cancerous tumors.*

Renato Dulbecco refers to this theory as "protective infection." The significance of Dulbecco's concept is that it is possible to grow in the laboratory cells that have been infected by tumor-causing viruses. This simplifies the process of understanding the nature of malignancy and experimenting with possible treatments. It is easier to experiment with different chemical treatments using cancer cells **in vitro** than in the human body. His theory and laboratory techniques advanced cancer research.

In 1986 Dulbecco published a paper "A Turning Point in Science" that appeared in the magazine *Science*. Dulbecco pointed out that to learn more about the science of cancer it will be necessary to know more about the human cellular genome. This paper was published shortly after a group of scientists met in 1985 to discuss the possibility of sequencing the complete genome of humans. This was a huge task spurred on by this important paper that was completed in 2003. Dulbecco moved back to Italy in 1993 where he became director of the National Council of Research in Milan. In early 2006 he left Italy and retired, at the age of 92, to La Jolla, California. He continues to follow the latest advancements in cancer research, primarily at the Salk Institute located in La Jolla.

See also Baltimore; Gallo; Temin

DUMAS' SUBSTITUTION THEORY: Chemistry: *Jean Baptiste André Dumas* (1800–1884), France.

An atom or radical can be replaced by another of known quantity that will produce the same result.

Jean Dumas believed that organic chemistry was similar to inorganic chemistry as related to the formation of **radicals** of the same types. Organic chemistry involves the element carbon in the construction of large molecules found in living tissues, such as large protein molecular compounds. Inorganic chemistry involves the reactions between and among all types of elements that form inorganic (nonliving) compounds. Radicals might be thought of as molecules that contain an electrical charge (similar to inorganic ions) and can act as units when combining with other elements or compounds, regardless of whether they are "organic" or "inorganic." An example is the hydroxyl radical OH−, which is part of the water molecule with a negative charge and is thought to have some effect on the aging of cells. Dumas contended that the site of these radicals is where replacements of atoms of one type for another take place. He showed that several different compounds that were composed of the same atoms or radicals exhibited similar characteristics. His famous example demonstrated that trichloroacetic acid was a similar compound to acetic acid. Dumas contributed to the advancement of chemistry with his work with atomic weights based on whole numbers as multiples of hydrogen as 1, and thus carbon as 12. This led him to his theory of types, which today is referred to as *functional groups of elements*. Historically, the credit for the theory known as the *theory of types* was disputed between Dumas and Auguste Laurent.

See also Dalton; Laurent

DYSON'S THEORY OF QUANTUM ELECTRODYNAMICS: Physics: *Freeman John Dyson* (1923–), United States.

Quantum theory can explain the relationships and interactions between minute particles and electromagnetic radiation.

Quantum electrodynamics, known as QED, is a theory that is relativistic in the sense that the subatomic particles in a field are rapidly changing their values (sometimes referred to as the ''jitters'') due to their constantly changing movements at their small submicroscopic scale. This leads to problems of measurement of exactly where they are at any particular moment and exactly how they are moving. This involves many possibilities and requires the use of mathematical probabilities as the only way to arrive at a single outcome. In other words, there is ''uncertainty'' introduced when measuring a particle's position (location) and momentum (unending movement) when being observed. In the 1920s and early 1930s this problem led to the development of the theory of quantum mechanics that solved this problem by using mathematical probabilities to describe the realm of atoms and subatomic particles. By the late 1920s quantum mechanics that dealt with single particles was expanded to include quantum fields as well. By the 1940s this research led to combining particles and fields that is known as QED. Those involved in the research at that time were Richard Feynman, Freeman Dyson, Julian Schwinger, and Sin-Itiro Tomonaga. (All but Dyson received a Nobel Prize for this work.) QED was the first viable quantum description of a physical field that involved quantum particles that can calculate observable quantities at this physical scale.

Freeman Dyson combined several related theories into a general theory that described the interactions between waves and particles in terms of quantum concepts (*see* Planck for a description of *quantum*, which means "how much"). This single theory enabled scientists to better understand quantum electrodynamics based on the traditional ingredients of particles and fields that synthesize waves, particles, and the interactions of radiation with electrons and atoms. This theory is also known as the *quantum theory of light or radiation*.

See also Dehmelt; Einstein; Feynman; Planck; Schwinger

E

EDDINGTON'S THEORIES AND CONCEPTS: Astronomy: *Sir Arthur Stanley Eddington* (1882–1944), England.

Eddington's star equilibrium theory: *For a star's equilibrium to be maintained, the inward force of gravity must be balanced by the outward forces of pressure caused by both the gas and radiation produced by the star's fusion reaction.*

Sir Arthur Eddington also developed the system indicating that heat that was generated inside stars was not transmitted outwardly by convection—as heat could be on Earth—but rather by a form of radiation. This theory of equilibrium not only explained why stars do not usually explode, but also provided a much better understanding of the internal structure of stars. It was William Higgins who determined that the sun (also a star) as well as all stars, and presumably the entire universe, are composed of the same basic elements as is Earth, with carbon being the most important of the first elements formed whose atoms were larger than hydrogen and helium. Our sun consists of several layers that are not sharply divided. The inner layer or core of the sun is about 250,000 miles in diameter and consists of hydrogen undergoing fusion to form helium, resulting in great quantities of energy in the form of radiation. The core's temperature is about 27,000,000°F; its pressure is about 7,000,000,000,000 pounds per square inch. (The air pressure on the earth's surface is less than 15 pounds per square inch.) The next layer or "shell" is the convection zone that surrounds the core, which transmits the radiation generated in the core to the outer layers. The photosphere, which means, "sphere of light," is the surface layer where the radiation is converted to light and heat as we know it on Earth. It is about five hundred miles thick, with a temperature of almost 10,000°F. Light and heat as well as other forms of electromagnetic radiation are constantly sent outward in three dimensions from the convection zone to the photosphere. The *chromosphere*—the outer "shell" or layer—is about two thousand miles thick with a variable temperature ranging from about 8000 to 90,000°F. The outermost layer is called the *corona*, which is a low-density collection of ionized gases. This layer forms the "spikes" that shoot out from the sun's surface and can be seen during an eclipse. As Eddington's theory of equilibrium states, if this arrangement becomes imbalanced, a star could explode. Exploding stars, which are extremely bright, were recorded in ancient history. Today, a very bright star that lasts only a few days or a week is called a nova, or supernova (*see also* Higgins).

Eddington's theory of star mass–luminosity relationship: *The more massive (very dense) the star, the greater its luminosity.*

The brightness of a star is determined almost entirely by its density (mass per unit volume). It is a fundamental principle of astronomy that for stars of constant mass, their luminosity is also constant. The mass of a star is related to its density but not necessarily to its size. Therefore, a small, high-density star is also massive in the sense that it may contain more matter than a star that is larger but less dense. A small, dense star may be much brighter than a very large star of low density. Up to the time of this concept, only masses of binary stars could be directly calculated—that is, a pair of stars close enough in proximity that their mutual gravity causes them to rotate around a common, invisible center of gravity. This led to the theory that stars, even of different spectral classes, with the same masses also had the same luminosities. This relationship of mass to brightness was of great significance in not only determining the nature of stars but also their distance from Earth. Using this mass-luminosity theory, along with the gravity-equilibrium theory, Eddington calculated there was a limit to the size of stars which is about ten times the mass of our sun. Any star forty to fifty times the mass of the sun would be unstable due to the excessive internal radiation. Eddington's mathematical equations are considered fundamental laws of astronomy and provide a new way to look at the evolution of stars, including our sun.

Eddington–Adams confirmation of Einstein's special theory of relativity: *Albert Einstein predicted light from distant bright stars would be "bent" by the gravity of another star as it passed by that star.*

Eddington reported that during a total eclipse, the light from several bright stars was slightly bent as their light came past the sun. This demonstrated that light exists as quantum bits called photons as predicted by Einstein, as well as waves of electromagnetic radiation that are affected by the gravity of the sun (*see* Figure E1 under Einstein). Eddington's work confirmed Einstein's theory of special relativity. The American astronomer Walter Sydney Adams (1876–1956) further tested the theory by measuring the shift in the wavelength of light from Sirius B, a very dense white dwarf with strong gravity. Einstein predicted the light from a massive star would shift to the red end of the spectrum. Thus, as the light from a massive star was slowed due to that star's gravity, a reddish shift occurs in the star's light (not to be confused with the **Doppler effect** for the "redshift," which is based on the lengthening of the frequency for light waves from a star that is rapidly receding from us) (*see also* Doppler; Einstein).

Eddington's constants for matter: *The total number of protons and electrons in the universe is* 1.3×10^{79}*, and their total mass is* 1.08×10^{22} *masses of the sun.*

Eddington arrived at these figures after considering the concept of an ever-expanding universe with "curved" space as theorized by Einstein. This theory was based to some extent on the tremendous velocities of nebulae. Eddington extended this theory and combined it with the theory for the atomic structure of matter to calculate his constants by theory alone. These are considered fundamental constants of science, which are important for the concept of an expanding universe.

Eddington's physical theory of the big bang: *The universe started to expand in all directions when a small, very dense point of energy (and possibly matter) exploded with tremendous force.*

Eddington was not the first to come up with a "cosmic egg" concept of the origin of the universe. This "egg," about the size of a marble or less, was assumed to be extremely dense as it contained all the mass-energy in the universe. Eddington's contribution was in developing the mathematical equations to explain the physics of the expanding universe. The concept goes back thousands of years, but it was Willem de Sitter (1872–1934), the Dutch mathematician/physicist/astronomer, who first developed a viable cosmological model based on the theory of an expanding universe. In 1964 Robert Woodrow Wilson and Arno Penzias of the Bell Telephone Laboratories detected cosmic microwave remnants of a hot primeval fireball as evidence of the big bang. Although some of the details of the big bang are still elusive, the concept of an inflationary universe is now accepted by most astronomers. It theorizes that at the time of the bang, all the original particles and energy could defy the speed of light and expand at any speed. Several other scientists have contributed to the cosmic egg/big bang/inflationary universe concept. There are still questions as to the origin and state of the nascent universe: What existed before the big bang? Is the universe really expanding? If so, do we really know the rate of expansion? Will it continue to expand forever? Will it reach equilibrium, then contract and start all over again? Will it regenerate or is it continually generating new matter? Is it static?

See also Dicke; Gamow; Hale; Hubble; Lemaître

EDISON'S THEORY OF THERMIONIC EFFECT: Physics: *Thomas Alva Edison* (1847–1931), United States.

> *Thermions (negatively charged electrons) generated at the hot cathode filament (of the light bulb) will jump to a cooler wire some distance from the filament.*

This is commonly referred to as the "Edison effect" and is the only physical theory Edison developed. All of Edison's other accomplishments were inventions that led to the development of important industries.

In developing his light bulb, Edison followed the lead of Sir Joseph Wilson Swan (1828–1914), the English physicist and chemist, who developed the first light bulb and was the first to use a carbonized (charred) thread as a filament. Swan's bulb did not work very well because he could not produce a good vacuum inside the bulb, nor could he develop a battery to produce a strong enough current to cause the carbonized thread to incandesce (glow white hot and give off light). Just one year before Edison announced his invention, Swan refined his carbon filament incandescent bulb and demonstrated it to the public. Given this set of circumstances, Swan should really have been given credit for the invention because he demonstrated his light bulb before Edison perfected his model. Even so, Edison is generally credited with the invention, although sometimes Swan is listed as a coinventor of the incandescent light bulb.

Edison was the first to explain that electric current flows in only one direction—from the filament to the electrode, and not the other way around. He experimented with several hundred different types of materials to act as filaments as he developed his incandescent light bulb. In 1883 he inserted a metal wire next to the filament, but not

One of Thomas Edison's major contributions to research was his establishment of private, independent research laboratories. His first was in Menlo Park, New Jersey, that contained a large library and expensive equipment and was staffed by over twenty technicians, including mathematicians and physicists. This laboratory produced many inventions that led to new industries and products that are widely used to this day. One for which he was internationally famous was the phonograph. His original model was a cylindrical device that recorded sound with a needle that formed the sound's imprints on tinfoil. Edison is also credited with the invention of many other devices, including moving pictures, types of office equipment, the storage battery, and many more. He received over one thousand patents in his lifetime and is considered the icon of inventors (although Nikola Tesla's inventions are equally important in today's world). After coinventing the incandescent light with Swan, he raised enough money to form the Edison Electric Light Company that was limited to small sections of New York City because his system generated direct current unlike the alternating current system devised by Tesla that could send current over long distances. Tesla's system was the beginning of today's large-scale power stations and national electric distribution systems. In 1887 Edison moved his laboratory to a larger facility in West Orange, New Jersey, and later established another laboratory outside of Fort Myers, Florida.

connected to it or the source of electricity. His expectation was that such a "cold" piece of metal would reduce the amount of air, thus improving the vacuum and prolonging the life of his filaments. He noticed that some electrons (he called them *thermions* because the filament was hot) flowed across the space gap in the bulb to the cooler metal wire, producing a noticeable glow. He patented his "Edison effect" but did not exploit it. Later, this arrangement of the filament next to a metal grid proved to be a valuable design for the development of the electronic vacuum tubes used in radios and early television sets before the days of semiconductors and transistors. His two-filament tube was called a diode. Later others added a small grid of wires between Edison's hot negative filament and the cool positive metal plate. This design became known as a triode. Over the years the Edison effect has been redesigned using semiconducting metals (instead of hot glass tubes) to construct small triode-like chips used in the integrated circuits for computers and other electronic devices.

See also Bardeen; Esaki; Tesla; Shockley

EHRLICH'S "DESIGNER" DRUG HYPOTHESIS: Chemistry: *Paul Ehrlich* (1854–1915), Germany. Paul Ehrlich was awarded the 1908 Nobel Prize for Physiology or Medicine.

Using the molecular structure of synthetic compounds, specific pharmaceutical drugs can be designed and produced to treat specific disease.

Aware of the aniline dyes (coal tar dyes) developed by the English chemist Sir William Henry Perkin (1838–1907) and how different dyes could stain animal fibers (e.g., wool and hair), Paul Ehrlich assumed these dyes could also differentially stain human tissue, cells, and components of cells. Using an aniline dye, scientists saw for the first time the chromosomes of cells, which Ehrlich called *colored bodies*. Other scientists identified specific germs that caused specific diseases. Ehrlich then hypothesized that because specific dyes will stain specific tissues selectively, it might be possible to design a chemical to attack specific types of germs that are also composed of specialized living material. This led to the theory that certain substances could act as "magic bullets" and attack specific disease-causing organisms while not attacking normal healthy cells in the body. He also formulated his side-chain theory of immunity, which led to the development of synthetic chemical compounds designed specifically to attack microorganisms, and thus enable the body to establish immunity to those specific microorganisms. Although many coal tar dyes can cause disease, including some cancers, the large dye molecules can be manipulated to attack specific types of bacteria, such as those that cause sleeping sickness and syphilis. However, drugs derived from coal tars were not effective for treating other diseases, including streptococci and cancer.

Ehrlich demonstrated that toxin–antitoxin reactions are not only a chemical reaction but, like most chemical reactions, these specific types of reactions can also be accelerated by heat or retarded by cold. He also was able to develop a standard for which antitoxins could be more accurately measured. His work in immunology provided Ehrlich the information necessary for him to arrive at his theory for side-chain immunity.

Paracelsus, the sixteenth-century alchemist, was known as the ancient founder of chemotherapy; Ehrlich is known as its modern founder.

See also Koch; Domagk; Elion; Paracelsus

EIGEN'S THEORY OF FAST IONIC REACTIONS: Chemistry: *Manfred Eigen* (1927–), Germany. Manfred Eigen shared the 1967 Nobel Prize for Chemistry with George Porter and Ronald Norrish.

> *Ionic solutions in equilibrium (same temperature and pressure) can be disarranged out of equilibrium by an electrical discharge or sudden change in pressure or temperature resulting, within a short time, in the establishment of a new equilibrium.*

Manfred Eigen used the "relaxation technique" along with ultrasound absorption spectroscopy to determine that this reaction occurred in 1 nanosecond (one-billionth of a second). Using this information and his techniques for measuring fast reactions, he ascertained how water molecules are formed from the H^+ (hydrogen ion) and the OH– (hydroxide ion) to form H_2O, or (H-O-H). He continued to use his "fast reaction" theory to explain complex reactions and characteristics of metal ions and, later, more complex organic biochemical reactions and nucleic acids. The theory of fast ion reaction is important to the understanding of chemical reactions in all types of living organisms. Understanding the steps involved in a series of mechanisms of fast reaction led to the development of the theory for the understanding of acid-base reactions.

Following his work with fast reactions Manfred Eigen turned his attention to problems dealing with biochemistry, particularly with the chemistry involved with the storage of information in the central nervous system.

EINSTEIN'S THEORIES, HYPOTHESES, AND CONCEPTS: Physics: *Albert Einstein* (1879–1955), United States. Albert Einstein was awarded the 1921 Nobel Prize in Physics.

Einstein's theory for Brownian motion: *The motion of tiny particles suspended in liquid is caused by the kinetic energy of the liquid's molecules.*

In 1827 the Scottish botanist Robert Brown (1773–1858), while using a microscope, observed that pollen grains suspended in water were in constant motion, which he believed was caused by some "life" in the pollen. He added minute particles of nonliving matter to water and observed the same motion. This phenomenon was not explained until the kinetic theory of molecular motion was discovered. Albert Einstein derived the first theoretical formula to explain why these small particles moved in a liquid when the particles themselves were not molecules. His equation was based on the concept that the average displacement of the particles is caused by the motion resulting from the kinetic energy of the molecules in the liquid. This resulted in a better understanding of the atomic and molecular activity of matter, and thus heat.

Einstein's theory of the nature of light: *Electromagnetic radiation propagated through space (vacuum) will act as particles (photons) as well as waves since such radiation is affected by electric and magnetic fields, and gravity.*

James Clerk Maxwell developed an equation stipulating that electromagnetic radiation can travel only as waves. This concept disturbed Einstein, as did the experiments by Philipp Lenard who had observed the photoelectric effect of ultraviolet light "kicking" electrons off the surface of some metals. It was determined that the number of electrons emitted from the metal was dependent on the strength (intensity) of the radiation. In addition, the energy of the electrons ejected was dependent on the frequency of the radiation. This did not jibe with classical physics. This dilemma was solved by Einstein's famous suggestion that electromagnetic radiation (light) flows not just in waves but also as discrete particles he called *photons*. Max Planck referred to these as *quanta* (very small bits). Using Planck's equation, $E = \hbar v$, where E stands for the energy of the radiation, $\hbar$ is Plank's constant, and v is the frequency, Einstein was able to account for the behavior of light as massless particles with momentum (photons) that have some characteristics of mass, for example, momentum (mass $\times$ velocity), as well as characteristics of waves. It resulted in Einstein being awarded the 1921 Nobel Prize for Physics.

Einstein's concept of mass: *The at-rest mass of an object will increase as its velocity approaches the speed of light.*

When a body with **mass** is not moving, it is at rest as far as the concept of inertia is concerned, meaning it is resistant to movement by a force. An analogy would be sluggishness, inertness, or languidness in a human being. Once an at-rest mass is in motion (i.e., **velocity**), it attains momentum (mass $\times$ velocity). When there is an increase in its velocity, there is also an increase in the body's mass. Thus, if a mass attained the speed of light, it would not only require all the energy in the universe to accomplish this, but also would equal all the mass in the entire universe. Therefore, it is impossible for anything with mass (except electromagnetic radiation, i.e., light) to attain the speed of light. This is one reason that light must be considered as being both a wave and a particle.

Newton's three laws that relate to mass and motion represent a classical, mechanistic concept of the universe. Newton's laws are deterministic based on the conservation of mass that states that matter cannot be created or destroyed. Although **weight** is proportional to mass, the *weight* of an object varies as to its position in reference to Earth (or other body with mass in the universe) and thus gravitational attraction, whereas the *mass* of an object is independent of gravity. The mass of an object (matter) is the same regardless of its location in the universe and thus is independent of gravity. At the same time, one might say that in deep outer space, mass has near zero weight.

Einstein's theories of relativity ultimately changed the Newtonian concepts of mass and motion. In modern physics, the mass of an object changes as its velocity changes, particularly as the velocity approaches the speed of light. This phenomenon is not noticeable on Earth because our everyday velocities are far less than that of light. For instance, the at-rest mass of an object will double when it attains a velocity of 160,000 miles per second. This is approaching the speed of light, which is 186,000 miles per second, and even a very small mass is incapable of attaining the speed of light. When masses with extremely high velocities interact, nuclear reactions can occur, where mass can be converted into energy—thus the famous Einstein equation, $E = mc^2$, where E is the energy, m is the mass of the object, and c^2 is the constant for the velocity of light squared.

Einstein's theory of special relativity: *1) Physical laws are the same in all inertial reference systems. 2) The speed of light in a vacuum is a universal constant. 3) Measurement of time and space are dependent on two different events occurring at the same time. 4) Space and time are affected by motion.*

An inertial reference system is a system of coordinates (anywhere in space) in which a body with mass moves at a constant velocity as long as no outside force is acting on it. From this concept, other components of the special theory of relativity follow.

Albert Einstein's special theory of relativity provides an accurate and consistent description of events as they take place in different inertial frames of reference in the physical world, with the provision that the changes in space and time can be measured. He developed the special theory of relativity to account for problems with the classical mechanistic system of physics. Many people had (and still do have) difficulty understanding his theory. In essence he is not describing the nature of matter or radiation, although he recognized their association. His theory describes the world or event, as it might look to two individuals in different frames of reference. For example, in classical Earth-bound physics, a person in a car going in one direction at 50 miles per hour (mph) meets a car approaching from the opposite direction going 100 mph. This describes how the speeds of the two cars are observed and judged (measured) independently by another person standing by the side of the road and not moving. But this does not apply to the drivers of two approaching cars. The driver in a car going 50 mph would perceive a car approaching him from the opposite direction at 100 mph, as going at 150 mph. Conversely, a driver who is going just 50 mph and is passed by another car going 100 mph in the same direction will perceive the passing car as going just 50 mph. This is just common sense and can be proved with classical equations of adding and subtracting velocities, which is known as Galilean transformations. However, this is not how it works with electromagnetic radiation waves such as the velocity of light. Einstein's theory states that the time between the two events (of the cars) is dependent on the motion of the cars. The special theory states that there is no absolute time or space.

According to experiments by Albert Michelson and Edward Morley, the speed of light is independent of the motion (velocity) of its source or the observer. For instance, if both cars are traveling at astronomical speeds in space and one car is going twice as fast as the other car and both turned on a spotlight toward the approaching car, the light would travel the same speed in both (either) directions. One driver would not perceive the light as coming toward him at a greater speed than would the other driver because they would judge the combined speeds of 50 and 100 mph of the two cars on earth. In contrast to Earth-bound car drivers, Einstein stated that despite how fast you are going, the speed of light will be constant for all frames of reference. The drivers of the two "space" cars, regardless of how fast they are going, will be in two different frames of reference of both time and space, but the speed of light will remain constant.

Thus, from their individual frames of reference (points of view), they will not be aware of "Earth-bound commonsense" differences in their speeds. No matter how fast you go, the speed of light will always be the same, even if you are speeding in the same direction as the light being propagated. The theory later included the concept of the three Euclidean coordinates of space—width (x), height, (y), and depth (z)—with the addition of the coordinate of *time* to arrive at a space-time continuum as developed by Hermann Minkowski.

There is much confusion about the word "relativity." In science, it is used as something "relative" to something else that can be measured mathematically or statistically. Specifically, Einstein's special theory of relativity is related to frames of reference as measured for the four coordinates of space and time (*see also* Minkowski).

Einstein's principle of gravity: *Gravity is the interaction of bodies equivalent to accelerating forces related to their influence on space-time. Gravity measurably affects the space-time continuum.*

There are two related concepts of gravity: the Newtonian classical concept and the Einsteinian concept related to his theories of relativity. Newton's law states that the gravitational attraction between two bodies is directly proportional to the product of the masses of the two bodies and inversely proportional to the square of the distance between them, as expressed in $F = G\, m_1 m_2 \div d^2$. Following is an example that relates acceleration to the force of gravity on Earth. If you are in a train or car that is traveling on a perfectly smooth surface and cannot see out the windows, you cannot tell if you are going backward, forward, or not moving at all if the vehicle is traveling at a uniform speed. But if the vehicle accelerates or decelerates, your senses will react as if gravity is affecting you. A person also becomes aware of G forces (simulated gravity) when a car or airplane rapidly accelerates. To sum this up, classical physics stated that all observers, regardless of their positions in the universe, moving or stationary, could arrive at the same measurement of space and time.

Einstein's theories of relativity negate this concept because the measurements of space and time are dependent on the observers' *relative* motions regardless of their inertial frames of reference within space coordinates. Einstein combined the ideas of several other physicists and mathematicians that dealt with non-Euclidean geometry, the space-time continuum, and calculus to formulate his gravitational theory. In essence, Einstein's concept of gravity affected space and time, as in his theory of general relativity. Even so, Einstein's concept of gravity was not quite correct because he did not take into account the information developed by quantum theory for very small particles and their interactions, even though these subatomic particles are much too small (or even massless) to be affected by Earth's gravity. His concept dealt with the macro (very large) aspects of the universe. As with all other laws of physics, the laws concerning gravity are not exact. There still is room for statements that more precisely interpret the properties of nature. For Einstein, the interactions of bodies are really the influence of these bodies (mass) on the geometry of space-time.

For many decades, scientists have tried to explain gravitational waves in relation to the theories of relativity or some other principle. *How* gravity acts on bodies (mass) can be described, but exactly *what* gravity is or *why* it is has not been discerned. Another hypothesis is based on the theoretical particle called the **graviton**, proposed by quantum theory. Gravitons behave as if they have a zero electrical charge and zero mass. Although assumed to be similar to photons, they do have momentum (energy). The concepts of gravity waves and gravitons are still under investigation. Recently, there have been several experiments designed to detect the graviton. The space

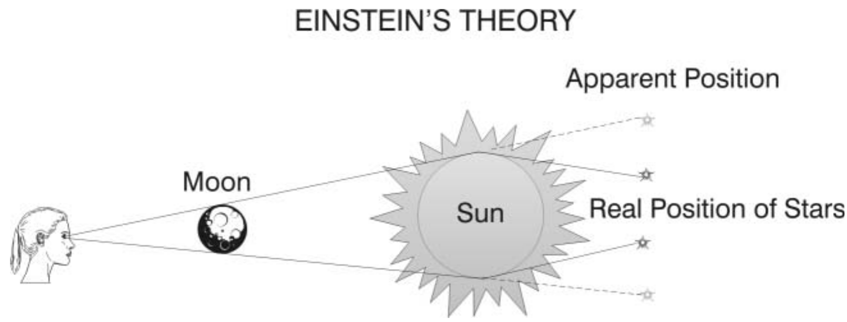


Figure E1. Einstein predicted that light from stars located behind the sun can be viewed during an total eclipse. As the star's light passes the sun, it is bent toward Earth by the sun's gravity, indicating that light has momentum (mass x velocity) and thus is affected by gravity leading to the theory that light is composed of minute packets (quanta) (i.e. photons). (The actual bending of the light is less than depicted in the diagram.)

satellite Gravity Probe B was launched in 2004 and lasted until 2005 when the data analysis started. It was designed to measure general relativity's predicted "frame-dragging" effect by measuring the space-time curvature near the Earth. Also, National Science Foundation (NSF) has funded two land-based installations designed to directly detect gravity waves on Earth. The Laser Interferometer Gravitational-Wave Observatory (LIGO) consists of two installations, one in Hanford, Washington, and the other in Livingston, Louisiana, that operate in unison as a single observatory. Other experiments to detect and measure gravity waves and gravitons are planned.

Einstein's theory of general relativity: *The interactions of mass (as related to gravitational force) are really the influence of bodies (masses) on the geometry of space and time. Space and time are affected by gravity.*

This theory is based on two main ideas: that the speed of light is a universal constant in all frames of reference and that gravitational fields are equivalent to acceleration for all frames of reference within the space-time continuum.

The first proofs of the general theory of relativity came from astronomy. It explained the previously unknown reason for the variations in the motions of the planets. The theory then was used to predict the bending of starlight as it passed massive bodies, such as the sun, and as it was detected during a total eclipse.

The theory also predicted that electromagnetic radiation in a strong gravitational field would shift the radiation to longer wavelengths. This was demonstrated by using the **Mössbauer effect**, which predicts the effects of a strong gravitational field on radiation. An experiment using a strong source of gamma radiation was set up just seventy-five feet above Earth to measure the gamma rays as they approached the surface of Earth. A minute lengthening of gamma rays (very short wavelength electromagnetic radiation) caused by the gravity of Earth was detected, thus confirming the theory.

Einstein's unified field theory: *A simple general law combining the four forces of nature (the electromagnetic force, gravitation, the strong force, and the weak force):*

1. *An electromagnetic force is exerted between electrical charges and magnetic fields.*
2. *Gravitational force is related to mass and acceleration and can affect electromagnetic radiation.*

3. *The* **gluon** *of the strong force holds the nuclei of atoms together. The positive protons and quarks in an atom's nucleus would repel each other and fly apart if it was not for the ''glueballs'' of the strong force that ''bind'' the quarks and protons.*
4. *The weak force is responsible for the slow nuclear processes that produce radiation, such as beta decay of the neutron to generate high-speed electrons.*

Albert Einstein spent the last thirty years of his life attempting to combine these four fundamental forces and the equations incorporating them into a general unified theory (GUT). He never achieved this goal. Einstein did not completely accept the new quantum theory, which did not lend itself to his concept for a unified field theory. One reason for not completely accepting quantum mechanics was because of the concept of indeterminacy where the exact position and momentum of a particle could not be determined at the same time. Thus, he considered that the "fuzziness" of matter was inconsistent with his concepts of relativity and the real world.

Toward the end of his life and later, physicists used **particle accelerators** to separate and identify numerous particles and forces from atoms and their nuclei, which made the unified field theory impossible. But the idea is not completely dead. Today there are several efforts to combine or find symmetry between various theories of matter and energy. Some examples follow:

- *The grand unification theory (GUT)*: an attempt to derive an equation to combine the strong and weak forces and explain how the particles of matter were dispersed from each other at the time of the big bang at speeds greater than the speed of light. The GUT has led to another concept referred to as the *inflationary universe*.
- *The theory of everything (TOE)*: an attempt to state that there is only one simple force and one ultimate particle in the universe. They have not been found.
- *The string theory*: a mathematical concept to explain everything in the universe with just one theory, based on the premise that all elementary subatomic particles are really strings that are single-dimensional loops, sometimes described as a doughnut folded over itself several times. Presumably the string theory has as few as ten or as many as twenty-six dimensions (not the three coordinates plus time with which we are familiar). Thus, it may not be related to the real universe but is an intriguing concept for mathematicians and theoretical physicists. When various mathematical equations and techniques are used to combine other mathematical equations into one final statement, the results always seem to come out as noise or lead to infinity.

Even before his work on relativity and gravity he published several important papers before and during 1905 that addressed areas of theoretical physics that changed many scientific concepts of physics.

In summary, these papers addressed the following topics:

1. One of his first papers dealt with the atomistic nature of the new science of thermodynamics. He considered the mechanical (Newtonian) view of the world intricately related to the second law of thermodynamics.
2. His next paper was the use of this concept to explain the Brownian motion of microscopic particles suspended in a fluid that led to the concept of the kinetic theory of motion and heat.

3. At the age of sixteen he wrote a paper explaining how time and motion are related to the observer if the speed of light is constant. This paper might be called the "seed" of his theories of relativity.
4. He published several papers that addressed why the Newtonian and Galilean laws of gravity, time, and space required an inertial frame of reference, as well as the compatibility of Maxwell's equations and relatively.
5. He proposed a quantum hypothesis, particularly for light (photons). Even though this led to the development of quantum mechanics, and so forth, he had some difficulty in trying to incorporate relativity, gravity, quantum theory, and other ideas into an overall grand unification theory (GUT). Scientists are still trying to arrive at a theory of everything (TOE).

> As a young boy Albert Einstein was shy but curious even though he did not talk until he was three years of age. He did not do particularly well in school except when he was introduced to subjects dealing with nature. He had an ability to understand mathematical concepts and taught himself Euclidean geometry at twelve years of age. He left school at age fifteen but later entered a school in Switzerland. However, he disliked the methods of formal education and spent much of his school years studying physics on his own and playing his violin. He passed his graduation exams by studying his classmates' notes but was not recommended for graduate education. He spent two years tutoring students and later was hired as an examiner in the Swiss patent office in 1902. He was married in 1903, had two sons, was divorced, remarried, and reportedly had ten mistresses later in life. He received his doctorate from the University of Zurich in 1905. He believed it important to simplify and unify the system of theoretical physics.

See also Eddington; Galileo; Minkowski; Newton

EINTHOVEN'S THEORY THAT THE HEART GENERATES AN ELECTRIC CURRENT: Biology: *Willem Einthoven* (1860–1927), Netherlands. Einthoven was awarded the 1924 Nobel Prize for Physiology or Medicine.

An accurate measurement of the electrical responses of the human heart can be made by viewing the magnetic lines of force that are proportional to the strength of the current that is produced by the heart, and thus indicating specific conditions of the heart.

Willem Einthoven was not the first to consider that the living tissue of animals produces an electrical current that can be measured. In the eighteenth century Luigi Galvani experimented by touching a frog's leg with a discharge from a static electric machine. He then tried clamping a dissected frog's spinal cord and leg with a brass hook onto an iron railing during an electrical storm. The frog's muscles twitched. His deduction, which proved incorrect, was that the electricity was produced by the frog's tissue. Alessandro Volta, a contemporary of Galvani believed Galvani's theory to be flawed and set out to test the hypothesis. Volta demonstrated that, in actuality, a slight current was generated when two dissimilar metals (brass and iron of Galvani's original experiment) were brought together under moist conditions irrespective of the frog's tissue. In the late 1800s Augustus Waller (1856–1922), the French-born cardiologist, was the first to detect, as well as the first to attempt to measure, the electric current generated by the heart. Waller used a special type of meter to measure millivolts produced by the beating heart. His device was complicated to use as well as inaccurate unless the electrodes were actually placed directly on the heart. Waller's device also required a series of mathematical calculations.

In 1901 Einthoven developed a series of prototypes that were called "string galvanometers." They were complicated, but they worked. His string devices used a thin conductive wire filament suspended between a strong electromagnet. When a small current was passed through the wire in the magnetic field, the wire filament would move slightly. By shining a light on the wire string a shadow would be cast that could make an image on a moving roll of photographic paper. His original string galvanometer weighed six hundred pounds, was water cooled to keep the powerful electromagnets cool, and required five people to operate it. Despite all these drawbacks, it was the first machine that could, with some degree of accuracy, measure the condition of the heart through the chest wall without attaching electrodes directly to the heart. Einthoven used his galvanometer to study and describe many cardiovascular disorders. The early string galvanometer was, over the years, improved to what we now call an electrocardiogram or electrocardiograph (ECG or EKG) machines that are relatively small, portable diagnostic devices that can accurately determine many possible conditions of the human heart.

See also Galvani; Volta

EKMAN'S HYPOTHESIS OF THE CORIOLIS EFFECT ON OCEAN CURRENTS: Geology (Oceanography): *Vagn Walfrid Ekman* (1874–1954), Sweden.

> *The effect of Earth's rotation as well as other factors on ocean currents is more evident at the poles than at the equator.*

In the 1890s the Norwegian Arctic explorer Fridtjof Nansen (1861–1930) made an important observation. While sailing in the Arctic regions, he noted that drift ice did not move in the direction of the wind but rather deviated 45 degrees to the right. Ekman used this information in a 1905 publication "On the Influences of the Earth's Rotation on Ocean Currents" in which he described the complex forces responsible for ocean currents. After observing ocean currents near the equator and the Arctic Circle, Ekman noted that near-surface water moves in the opposite direction to the motion of the surface water resulting in a movement of water at right angles to the wind directions. In the Arctic the motion of the ice floes were determined by the currents that in turn were produced by a complex interaction between the forces of the surface wind, the friction between the different layers of water in the oceans, and most important, the rotation of the earth. The results of these complex forces creating variations of water velocity with depth of forces became known as the *Ekman spiral*.

The Ekman Spiral is also a good example of the Coriolis force interacting with other forces. Sir George Biddell Airy based his theory of internal waves and *dead water* on the work of Vagn Walfrid Ekman. The region of *dead water* in the oceans is caused by a thin layer of freshwater that is produced by melting Arctic freshwater ice spreading over the sea that forms waves between the layers of fresh and saltwater that are at different concentrations, thus at different densities. This phenomenon has been known to slow down or even stop a sailing ship's progress. In 1903 Ekman developed what is known as the *Ekman current meter* to detect and measure the differences in ocean

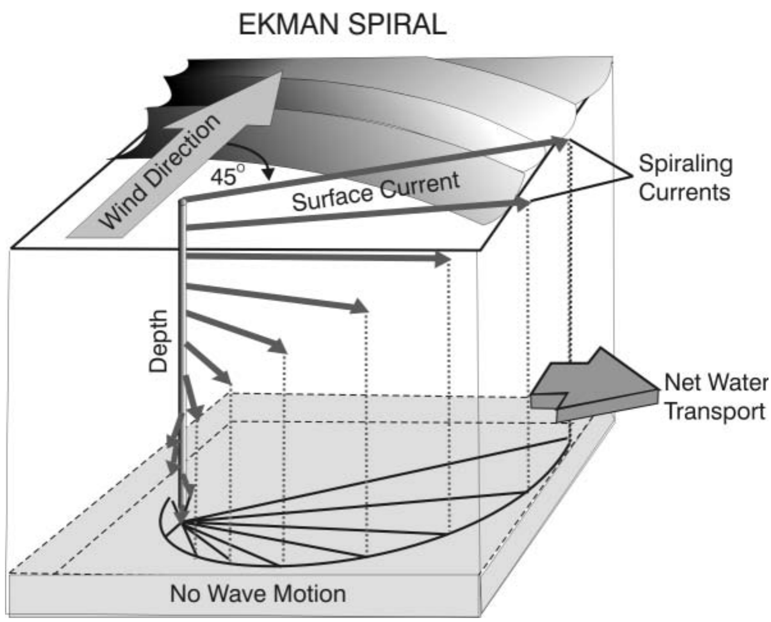


Figure E2. Several forces (surface winds, Coriolis Force, layers of water, etc.) create complex variations of water velocity and direction at various depths.

currents. It could also measure the strength and direction of ocean currents. Over the years it was improved. Today, high-precision instruments are used to measure various factors affecting ocean currents.

See also Airy; Coriolis

ELDREDGE–GOULD THEORY OF PUNCTUATED EVOLUTION: Biology: *Niles Eldredge* (1943–) and *Stephen Jay Gould* (1941–2002), United States.

Evolution of species and individuals by natural selection results from pressure brought about by relatively rapid changes in the environment.

The paleontologists Eldredge and Gould found 1) patterns in the fossil records indicate the abrupt appearance of new species, 2) evidence suggests the relatively stable **morphology** of present species, 3) there is wide distribution of transitional fossils, 4) there are apparent differences in the morphology between older "parent" species and current "daughter" species, and 5) distinct patterns can be found in extinct species. All of this evidence led to their theory of punctuated evolution.

Punctuated evolution is also referred to as *punctuated equilibria* or, at times, as *catastrophism*. Although still accepting many of the tenets of slow organic evolution, such as natural selection, their theory claims the evidence indicates that long periods of slow evolution were "punctuated" by very rapid environmental changes. Presumably, earthquakes, volcanoes, meteors or asteroid bombardments, or other catastrophes altered the atmosphere and thus the food supply and hastened other rapid changes in the environment. In other words, the abrupt appearance of a new species is the result of *ecological succession* and *dispersion*. One possible example is a 10-kilometer asteroid that impacted about sixty-five million years ago in Chicxulub, located in Mexico's Yucatan, which exploded dirt and other matter into the atmosphere, blocking sunlight. It is generally accepted as causing the elimination of most plant life on Earth. Once plant life was eliminated, so were the dinosaurs and many other animal species. Some primitive forms of life, such as bacteria, minute multicellular organisms, seeds, and small animals, survived and continued to evolve into new species. There are a number of large gaps in the fossil records of early organisms that indicate that evolution may not have been a continuous slow process, but new species were derived from the survivors of catastrophic ecological events. On the other hand, some of these gaps in the fossil records could be an indication that soft-bodied organisms were not fossilized during certain periods of Earth's development.

Today most scientists accept the concept that the continuing evolution of species is driven by natural selection. However, there is disagreement concerning the mechanisms of how and why new species appear, and how long it takes for genetic mutations and environmental changes to appear in organisms. One of the problems is "paleospecies" which makes a distinction between the classifications of ancient fossils as compared to the classification of the remains of species found in more recently observed populations. An incomplete fossil record may be created by several factors including geological and geographic changes, such as continental drift, mountain building, overlapping of stratified sedimentary layers of Earth, and other forces that have altered Earth's surface over time and amplifies the problem of paleospecies.

See also Buffon; Darwin; Gould; Lamarck; Wallace

ELION'S THEORY FOR CELL DIFFERENCES: Biochemistry: *Gertrude Belle Elion* (1918–1991), United States. Gertrude Elion shared the 1988 Nobel Prize in Physiology or Medicine with George Herbert Hitchings and James Whyte Black.

> *Nitrogen-based molecular compounds (purines) found in the nucleic acid of abnormal cells can be altered to cause death to the abnormal cells without causing death to normal cells, thus, a drug can be designed to kill the abnormal cells that cause normal cells to die.*

Gertrude B. Elion was born, raised, and educated in New York City during a period when few women joined the ranks of physicians yet alone research scientists. After receiving a degree in chemistry from Hunter College at the age of 19, she was unable to get into graduate school primarily because of financial considerations brought about by the Depression. However, she had a variety of jobs to pay for a master's degree in chemistry. She was the only female in the class of 1941 in New York University's master's degree program. During World War II when many men went off to war, a job opened at Burroughs Wellcome Laboratory working with Dr. George Hitchings (1905–1998) who allowed her to conduct her own basic research in virology and immunology. At this time she began her studies for a doctorate but never finished, which she always regretted.

While at Wellcome, she began studying nucleotides and purines and how they might be chemically altered and used as drugs for specific diseases. This was some years before James Watson and Francis Crick determined the structure of DNA.

The team of Elion and Hitchings developed several compounds designed to "cure" leukemia. They were tested on mice but proved to be too deadly for use on humans. By rearranging the structure of purine compounds, they developed the drug called 6-mercaptopurine (6-MP) that was approved for use with patients with terminal leukemia. It proved to be effective when used as part of a treatment with other drugs. Since 1988 about 80% of children suffering from acute leukemia can be considered as cured.

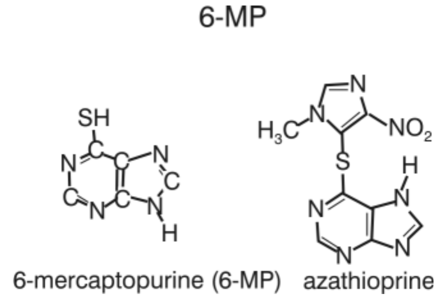


Figure E3. Elion and Hitchings altered a dangerous drug so it could be used to fight leukemia. They changed the structure of a purine compound to form a new drug called 6-MP that was more effective.

During the mid-twentieth century organ transplants were performed, but many of the transplanted organs were rejected by the recipient's own immune system. The immune system produces antibodies in white blood cells called lymphocytes that are designed to fight infections. Organs that were transplanted from one person to another were seen as "foreign" to the immune system (with the exception of organs from identical twins). Elion improved on the drug she called 6-MP so that it was more effective in controlling the production of the white blood cells. Thus, the immune system would not reject the implantation of the organ of one person to another. This made possible the thousands of organ implants performed today.

Elion, Hitchings, and the Scottish pharmacologist James Black (1924–) realized that a form of their designer drug 6-MP was altered in the body by an enzyme that also was responsible for the formation of uric acid. When the body produces an excess of uric acid, it results in a painful condition known as gout. A compound called allopurinol would block the production of uric acid and proved very effective for the control of excess uric acid and thus the relief of gout. Today, with modern medications gout is one of the easiest human conditions to treat successfully in a short period of time. Research at the Burroughs Wellcome laboratory continued to develop other designer drugs. Some were variations of the original 6-MP version designed specifically to control high blood pressure (Propranolol), gastric ulcers (Tagamet), and AIDS.

Upon retirement, Gertrude Elion worked for the World Heath Organization. Although she never received her PhD, she did receive many honors and several honorary doctorate degrees.

ELTON'S THEORY OF ANIMAL ECOLOGY: Biology: *Charles Sutherland Elton* (1900–1991), England.

As more species arrive in a given area, space and resources become a limiting factor, restricting the habitat and resulting in the extinction of some species while other species adapt to their limited (changed) environment.

Charles Elton, an early student of the science of **ecology**, performed many of his animal ecology studies on Bear Island off the coast of Norway. Elton named his concept "packing," evidenced by the island's limited number of existing species, which resulted from specialized evolution within the island's limited environment. He surmised that a species' place in the ecological environment is directly related to the availability of food as well as its predators. This idea led Elton to advance for the first time the concept of an interactive food chain, called a *food cycle* and often referred to as the *food web*. Bear Island's geology was suited to a limited number of plant species, which became food for the island's birds. The birds then became food for a limited number of the island's mammal species, which completed the island's community of species, and food chain. Because the mammals and most other species of organisms on the island could not migrate to escape any limitations of the packing imposed by environmental conditions, they would be subject to different evolutionary pressures than would exist if the animals were located in much larger, diverse environments. Animals living in an environment with a widespread limited number of species can "practice" environmental selection by migrating to change their habitat. Elton's theory of how a limited environment affects the types and distribution of plant and animal species is considered an important contribution to the theory of evolution. However, some question its applicability to humans despite humans' ability to change their environment to make it more suitable for habitation.

See also Darwin; De Vries; Dobzhansky; Haeckel; Wallace

ENDERS' THEORY FOR CULTIVATION OF VIRUSES: Microbiology: *John Franklin Enders* (1897–1985), United States. John Enders, Frederick C. Robbins, and Thomas H. Weller shared the 1954 Nobel Prize for Physiology or Medicine.

> *Viruses can be cultivated in test tubes by using selected live cells from animals with the addition of the penicillin antibiotic that will prevent bacterial growth in the culture, thus producing a safe and effective vaccine.*

John Enders, the son of a wealthy banker, attended Yale and Harvard Universities. While in college, he had difficulty in deciding on a career. In 1917 he left college to become a flight instructor during World War I. He later became a real estate agent and then entered Harvard to study languages. While at Harvard, he became interested in biology and changed his major to microbiology after entering Harvard Medical School.

Prior to 1948 whole live chick embryos, as well as the nerve cell tissues of live monkeys, were experimentally used to develop treatments for human viral diseases. However, the results were unsatisfactory. It was inconvenient and cumbersome to use live chick embryos, and live monkey nerve tissue created problems of rejection in the human body. John Enders established an Infectious Disease Laboratory in 1946 at The Boston Children's Medical Center and was the first to use just the living cells and not the entire living embryos in the development of viral cultures. In 1948, along with two other Americans, Frederick C. Robbins (1916–2003), a pediatrician and virologist, and Thomas H. Weller (1915–), also a virologist, he cultured the mumps virus using chick embryo cells mixed with ox serum and some added penicillin. He hypothesized that by adding penicillin to the viral culture, it would result in an attenuated virus, and thus a more effective treatment for several viral diseases would be possible. This was a continuation of the work on the mumps virus that he, along with several others, had begun in 1941. A similar improved technique was used to cultivate the poliomyelitis virus in 1949 and later in 1950 the measles virus. Enders, Robbins, and Weller received the Nobel Price in 1954 for their work on the poliomyelitis virus, an especially crippling and deadly disease of young children. Through their research, large quantities of the polio virus were produced and analyzed. Eventually this led to the mass manufacture and distribution of Sabin and Salk polio vaccines. It should be noted that the time period between the successful cultivation of a viral vaccine and its actual introduction into the general population is significant and not without setbacks. A successful polio vaccination program was not established until 1963; measles and mumps vaccine programs were developed in the late 1960s. Research on improvements to all these vaccines continued for sometime even after their widespread use.

See also Robbins; Sabin

EÖTVÖS' RULE (LAW): Physics: *Baron Roland von Eötvös* (1848–1919), Hungary.

> *There is a measurable relationship that relates surface tension, temperature, density, and the molecular mass of a liquid.*

This "law" explains why surface tension causes water to rise on the inside walls of a capillary tube (a capillary tube is a glass tube with a very small diameter hole through its length). This action is due to the rounded shape of drops of water that causes them to slightly rise on and cling to the inside surface of the glass tube forming a concave surface on the water. The same force applies to the shape of the surface water in a drinking glass, but it is not as noticeable. Evötös devised a unique technique and device called the *reflection method* that made it possible to compare and measure the surface tension of various liquids. Using this sensitive reflection device, he was able to determine the surface tensions of several liquids and thus calculate their molecular weights. This relationship became known as Eötvös' rule that, in essence, states: *The rate of change of molar surface energy with temperature is a constant for all liquids*. This rule is so fundamental to all liquids that it is compared to the universal gas law.

During the last decades of his life, Eötvös conducted detailed studies of gravity, magnetism, and geophysics in general. In 1888 he developed an instrument, called the "torsion balance," designed to measure and to determine any difference between inertial and gravitational forces. It was constructed as a bar with two weights made of different materials attached at the end of the bar by a thin torsion fiber (this is similar to Cavendish's experimental instrument used to measure gravity). Eötvös decided to use this instrument on the smooth surface of a large frozen lake so as to minimize topological features that might interfere with sensitive measurements on land. By 1903 he had collected measurements from forty different locations. Later, his torsion balance data from the lake measurements were used to determine that the lake's axis was parallel to a tectonic line. This was the first time such geological data was established by use of a torsion balance and is now considered the birth of the field of geophysics research.

Eötvös also developed an instrument called the "gravity compensator," which was somewhat similar to a *variometer* that is curved with deflectors at both ends. The instrument could be rotated around a horizontal axis with the deflectors oriented in a vertical position to measure a zero balance. By changing the position of the deflectors, gravity could be measured with some accuracy. He also was concerned with the two forces that affect mass—the inertial force that is apparent when a force accelerates a mass, and the gravitational force that the mass experiences due to attraction to another mass. He determined that the difference between inertial to gravitational mass is very small, something like 1 to 20,000,000.

The *Eötvös effect* was experimentally demonstrated by considering the motion of boats in the water, as well as the effects of gravity on the boats. This effect was based on his experiments that indicated the weight of a moving body on Earth's surface is dependent on its direction and speed. In other words, the weight of the boat on Earth's surface changed as a result of the direction and speed at which they were proceeding. This experiment was conducted by observing one boat heading east and one west. This Eötvös effect is important in the study of gravity.

Eötvös was also interested in measuring magnetism. Using his torsion balance he determined the **declination** and **inclination** of Earth's magnetic field at various points on Earth. Evötvös attempted, however unsuccessfully, to determine Earth's magnetic inclination in past eons of time. Today it is known that the geo and magnetic poles have shifted since the beginning of Earth's existence.

See also Cavendish

ERASISTRATUS' THEORY OF ANATOMY AND PHYSIOLOGY: Biology: *Erasistratus of Chios* (c.304–250 BCE), Greece.

> *A three-way network of veins, arteries, and nerves supplies every organ and other tissues of the body with vital fluids; and the brain is composed of two sections with many folds and convolutions.*

Erasistratus of Chios (or Kos), which is an island off the coast of Greece in the Aegean Sea, founded an independent medical school for the study of anatomy and physiology of the human body. As with all the ancients, Erasistratus' ideas were mixed with both correct and incorrect assumptions. For instance, he rejected the humoral theory and incorrectly believed that air was pulled into the body by the blood as the blood moved upward in the body. He rejected the belief that the body was filled throughout with three kinds of vessels (veins, arteries, and nerves), and in the extremities of the body these vessels became so fine that they were invisible (today, they are known as capillaries). He was correct in his general theories of how organs in the body functioned, but his concepts of the actual physiology were often wrong. The many mistaken concepts of anatomy and physiology of these ancient times were the result of the acceptance of the writings of others, theosophical reasoning, or simply inaccurate observation. One example was his correct belief that the veins transported blood, but that the arteries and nerve tissues transported "animal spirits."

Erasistratus was the first person to make a distinction between the main parts of the brain. He identified the cerebrum as the larger portion and the cerebellum as the smaller part. He was also the first to note that the human brain had more folds or convolutions and thus more surface area than did the brains of other animals. From this he correctly concluded that this larger surface area was partially responsible for the greater intelligence of humans when compared with animals. His theory that the brain was the seat of intelligence was at odds with Aristotle who considered intelligence to be in the heart.

Erasistratus also disavowed the occult and its forces. Rather, he explained the existence of matter in terms of "atoms" (as proposed by Democritus of Abdera). An example: To explain bleeding from arteries, he believed that a vacuum was formed in the artery as the blood flowed out and that the artery was filled with blood again by the connecting veins. In other words, a vacuum cannot exist—it must be filled with something (atoms of blood), and in this case more fluid from the veins. In addition, Erasistratus' concept of disease was opposite of the long-held beliefs of Hippocrates. Erasistratus' concept of disease was mechanistic in the sense that the blood, fluids, spirits, food, and so forth provided a means of blocking any inflammation of the vessels in the human body.

See also Aristotle; Democritus; Galen; Hippocrates

ERATOSTHENES' MATHEMATICAL CONCEPTS: Astronomy: *Eratosthenes of Cyrene* (c.276 BCE–194 CE), Greece.

Eratosthenes' theory of prime numbers: *From a list of ordered numbers (1, 2, 3, 4, 5, 6, 7, 8, 9,…) strike out every second number after 2, every third number after 3, every fourth number after 4, and so on. The remaining numbers in the original list will be prime numbers.*

Eratosthenes of Cyrene, a poet, historian, and mathematician, developed the system of filtering, which became known as the *sieve of Eratosthenes*. Using his "sieve" procedure, the prime number is a positive integer that has no divisors except the integer itself and the first number selected. For example, select 2, for which the next two numbers are 3 and 4. Strike out 4, which is an integral multiple of the original number 2. A prime number is a positive integer having no divisors except itself and the integer (where the integer is any number, except zero, used for counting).

Eratosthenes' concept of measuring the circumference of Earth: *At the summer solstice (June 21) when the sun is at its zenith in the city of Syene (Aswan), it will be 1/50th of a full circle when measured by the angle of the sun at the city of Alexandria at the same time on the same day.*

Eratosthenes of Cyrene knew that on June 21 the sun cast no shadow in the bottom of a water well in Syene. Therefore, on this date and at this point, the sun was at its zenith. At the same time, he measured the angle of the shadow from a stick placed upright in the ground at the city of Alexandria, which he knew was five thousand stadia from Syene (*stadia* is the plural for the Greek *stadium*, the unit of measurement based on the length of the course in a stadium. It is equal to about 607 feet). Eratosthenes knew how many stadia a camel can walk in one day, so to estimate the distance between the cities he multiplied the distance a camel walks in one day by the number of days it took a camel caravan to make the journey. We now know that Syene (now called Aswan) is about 800 kilometers or 500 miles southeast of Alexandria in Egypt. On June 21 at Alexandria the angle of the stick's shadow was 7°12', which corresponds to about 1/50th of a 360° circle. Multiplying 5,000 stadia by 50 equals 250,000 stadia as Earth's circumference. Eratosthenes' calculation was very close to today's accepted equatorial circumference of 24,902 miles.

Using similar measurements Eratosthenes was able to calculate the tilt of Earth to its axis (the ecliptic, which is the inclination of Earth's equator to its orbital plane) as 23°51'20", which is also close to the modern figure of 23.4 degrees. Modern calculations still use Eratosthenes' geometric and algebraic methodologies to arrive at the current figures.

Using his method it was also estimated that the distance between the earth and the sun was 804,000,000 stadia and the distance to the moon was 780,000 stadia.

ERNST'S THEORY OF THE MAGNETIC MOMENT OF ATOMIC NUCLEI: Chemistry: *Richard Robert Ernst* (1933–), Switzerland. Richard Ernst received the 1991 Nobel Prize in chemistry.

> *Atomic nuclei have a* ***magnetic moment*** *that will align with strong magnetic fields, thus submitting the nuclei to specific pulsating frequencies of radio waves that can alter the nuclei's magnetic moment.*

In the 1940s the Austrian–American physicist Isidor Rabi, Swiss physicist Felix Bloch (1905–1983), and the American physicist Edward Purcell developed the technology of nuclear magnetic resonance (NMR) to probe and study characteristics of the nuclei of simple molecules. Nuclei have a natural polarity that align themselves with strong magnetic fields. By exposing them to selected frequencies of radio waves, nuclei realign themselves in a new energy state. When the radio waves are removed, they return to their original energy state, giving off specific radiation that can be used to identify the nuclei.

Richard Ernst subjected larger protein (organic molecules) to pulsating high-energy radio waves, which provided a means to produce images of living tissue. The process was originally called nuclear resonance because it "excited" the nuclei of atoms. However, the name was changed because people still mistakenly connect the nuclei of atoms resonated by NMR with the nuclear energy released by the atomic bomb. Once the process was improved, with better imaging techniques that could view cross sections of the human body, a similar process became known as magnetic resonance imaging (MRI, which is still based on the magnetic moment of atomic nuclei). Magnetic resonance imaging provides a better series of images than X-rays. With no danger of radiation exposure, MRI is safer than X-rays because the radio radiation used is of a much longer wavelength and lower frequency than X-rays. The improved images have greatly assisted diagnostic procedures for the medical profession because of its ability to detect various abnormalities in the body more accurately than X-rays.

See also Mansfield

ESAKI'S THEORY OF TUNNEL DIODES: Physics: *Leo Esaki* (1925–), also known as Esaki Reona or Esaki Leona, Japan. Leo Esaki shared the 1973 Nobel Prize for Physics with Ivar Giaever and Brian David Josephson.

> *By doping semiconductors with selected impurities, the quantum wave-like nature of electrons could ''tunnel'' through barriers resulting in diode-like properties. In effect as the voltage increases, the flow of electrons in a circuit will decrease, and vice versa.*

Some background on Esaki's theory of tunnel diodes may help explain the theory and the tunneling device and how it works. When Thomas Edison was experimenting with his light bulbs, he observed that carbon from the filaments would darken the inside of the glass bulbs. He experimented with several solutions. One was to place a piece of metal alongside the filament (close, but not touching each other) with the expectation that the metal strip would collect the carbon rather than its being deposited on the inside of the glass bulb. This piece of metal was called a "plate," and when it received a positive charge (the filament was negatively charged by the battery), the current continued to flow even though there was a small space between the plate and filament. However, he noticed that if the plate received a negative charge instead of a positive charge, there was no flow of current. This phenomenon was later called the

"Edison effect" and was the only new scientific principle he discovered. Edison patented this phenomenon but never exploited his discovery. Later, others used this effect in devising what is known as the cathode ray tube where a hot filament gives off electrons. When a positive plate was introduced into the tube, the electrons would flow toward the plate similar to a completed electrical circuit even though there was no connection between the filament and plate. If the plate was negatively charged, there would be no flow of electrons to it by the filament, thus it would act as an "on-off" switch to control the flow of current (*see* Figure C6 under Crookes). In the 1880s John Ambrose Fleming "rediscovered" the Edison effect and called the device a "valve." Because it had two parts—the filament and plate—it was also called a diode because it had two elements and soon became familiar as the old-fashioned radio vacuum tube. In 1906 Lee De Forest (1873–1961), the American inventor, added a third filament made of fine wires in the form of a "grid" placed between the two-diode elements. This third filament grid could be supplied with its own flow of electrons and thus act to control the flow of electrons between the two filaments. Thus, the vacuum tube with three filaments became known as a "triode." In a diode, the electrons either flow or do not flow, similar to an on-off switch, whereas in a triode the flow of electrons can be "modulated" enabling the triode vacuum tube to act as an amplifier of current electricity, and as a receiving device to pick up and amplify radio and TV signals. Herein lies the gist of the next phase of the story of how the Edison effect led to the development of the tunneling diode switch at the quantum level by Leo Esaki.

In 1958 Esaki "doped" the element germanium. Doping is a process of adding specific impurities to elements that alter their semiconducting characteristics at the quantum level. Thus, as the voltage increases, the current (amount of electricity) decreases, thus allowing the flow of electrons to "tunnel" through what is known as the narrow p-n (positive-negative) junction barrier created by the electrons' valence state. Classical mechanics states that wave-like matter cannot pass through such barriers, but *by doping the semiconductors with selected impurities the quantum wave-like nature of electrons could "tunnel" through this barrier resulting in diode-like properties. In effect as the voltage increases, the flow of electrons in the circuit will decrease, and vice versa.* In other words the semiconductor now acts as a diode, but with several advantages over the vacuum radio tube. The tunnel diode is much, much smaller than the vacuum tube (today this type of diode is known as a semiconducting chip). They consume much less power, produce much less heat, and are much more reliable and last much longer. Other improvements in quantum-level microchips, transistors, and integrated circuits, and so forth have made the concept of tunneling diodes indispensable for today's many types of electronics with fast speeds, small sizes, and reduced internal "noise" created by the circuits as they use much less electric power.

See also Bardeen; Edison; Shockley

EUCLID'S PARADIGM FOR ALL BODIES OF KNOWLEDGE: Mathematics: *Euclid* (c.330–260 BCE), Greece.

It is postulated that all theorems must be stated as deductions arrived at as self-evident propositions or axioms for which a person can use only propositions already proved by other axioms.

First, some definitions:

- A *paradigm* in geometry is the general plan for the development of the logical statement. In science, it is referred to as a "ruling theory" or a "dominant hypothesis."
- A *postulate* claims something is true or is the basis for an argument, such as in geometry. Euclid set out five postulates: 1) A straight line can be drawn between two points. 2) A straight line can be drawn in either direction to infinity. 3) A circle can be drawn with any given center and radius. 4) all right angles are equal. 5) A unique line parallel to another line can be constructed through any point not on the line (parallel lines never meet).
- A *theorem* in mathematics is a proven proposition.
- *Deduction* is a method of gaining knowledge. A deduction is inferred in the statement "if-then" (from the general to the specific).
- A *proposition* is a statement with logical constraints and fixed values (e.g., if proposition A is true, *then* proposition B must also be true).
- An *axiom* is a self-evident principle that is accepted. Several equivalent synonyms for *axiom* are *primitive proposition*, *presupposition*, *assumption*, *beginning postulate*, and *a priori*. An example of one of Euclid's axioms is 1) things that are equal to the same thing are equal to each other; 2) if equals are added to equals, the wholes are equal; 3) if equals are subtracted from equals, the remainders are equal; 4) things that coincide with one another are equal to one another; 5) the whole is greater than any one of its parts. These five axioms can be summarized as, "The whole is equal to the sum of its parts."

Euclid's paradigm for knowledge led to his great achievement in the field of plane geometry. He brought together the many statements related to geometry into a logical, systematic form of mathematics. Euclid's *elements*, written in about 300 BCE, included thirteen books of what was then known in the field of geometry to which he applied his paradigm. It is still valid today.

EUDOXUS' THEORY OF PLANETARY MOTION: Astronomy: *Eudoxus of Cnidus* (c. 400–350 BCE).

To account for the irregular motion of the planets, earth must be at rest and surrounded by twenty-seven celestial spheres.

Eudoxus of Cnidus was one of the first ancient astronomers to attempt to account mathematically for the irregular motions of the planets and still maintain Earth as the center of the universe. His system required not only a motionless Earth, but also twenty-seven crystal-like celestial spheres. The sun and moon each had three spheres, and each of the known planets required four spheres to account for their motions. The outermost twenty-seventh sphere contained all the fixed stars; beyond that were the heavens (*see* Figure P5 under Ptolemy.) Eudoxus was able to describe mathematically the rising of the fixed stars and constellations over the period of one year.

See also Aristotle; Euclid; Ptolemy

EULER'S CONTRIBUTIONS IN MATHEMATICS: Mathematics: *Leonhard Euler* (1707–1783), Switzerland.

Euler's three-body problem: *The motions of an object moving three ways simultaneously can be predicted using Newton's three laws of motion.*

One example of how a body can move in three different directions at the same time is Earth's rotating on its axis, revolving about the sun, and proceeding as part of the solar system toward a distant galaxy. Leonhard Euler, interested in determining the motions of the moon, used analytical techniques that could be applied to the problem to derive a form of mechanics. He also devised a system to analyze how the three Newtonian laws of motion and gravity affected objects that exhibited three-way movements. Euler's equation was based on Newton's dynamics called the *mass point*, for a body that contains mass and is rotating about a point. Euler's equations of motion state that a set of three different equations will express the relationships between the 1) force of moments, 2) angular velocities, and 3) angular accelerations of a rigid but rotating body (e.g., Earth). From this he developed two theories for the motion of the moon that proved to be an asset for sea navigation. These motions of the moon were used before dependable clocks became available to determine longitude (*see also* Newton).

Euler's theory of notations: *It is possible to use notations such as sines, tangents, and ratios when the radius of a circle equals 1.*

Euler introduced notations in algebra and calculus that Lagrange, Gauss, Leibniz, Einstein, and others followed. He developed an infinite series of numbers that included notations such as e^x sin x, and cos x and the relation of $e^{ix} = \cos x + i \sin x$. Euler also wrote the first text on analytical geometry that explains such concepts as prime number theory, differential and integral calculus, and differential equations. The contributions made by Leonhard Euler are numerous, including several important mathematical equations, formulae, methods, constants, criteria, correlations, and numbers that were important to the development of mathematical theories by other mathematicians.

See also Einstein; Eratosthenes; Leibniz

EVERETT'S MULTIPLE-UNIVERSE THEORY OF REALITY: Physics: *Hugh Everett III* (1930–1982), United States.

> *The wave function of quantum mechanics describes alternate outcomes of events in the same universe.*

According to the Copenhagen interpretation of quantum mechanics, as proposed by Niels Bohr, the quantum mechanical wave function states that only a statistical probability is possible for any explicit event to occur. This traditional interpretation applies only to submicroscopic particles, not to the Newtonian macro world. Even Einstein had a problem with the quantum principle of uncertainty of determining a particle's position and momentum at the same time because at this level the principle of cause-and-effect may not apply. Hugh Everett proposed a different interpretation. He suggested that every possible outcome that may occur as an event could actually do so in the same universe, or possibly in multiple universes. Everett's interpretation, also referred to as the "many world interpretation" or the "relative-state model," discounts the Copenhagen interpretation of quantum wave function. His concept relates to as many large and small events and as many outcomes as one could possibly arrive at when measuring the universe. Some scientists discount his theory, but others are attempting to develop a new quantum theory that eliminates the special role of an observer from the process. It seems the observer may account for Heisenberg's uncertainty principle of indeterminacy. Therefore, if the observer is eliminated so might the uncertainty. Another possible means of justifying Everett's concept of a many-worlds universe is to use probability theory. The main objection to his theory is that it either requires many different outcomes from the same cause in one universe or it requires many parallel universes that do not communicate with each other.

See also Bohr; Feynman; Hawking; Heisenberg; Schrödinger; Schwarzschild

EWING'S HYPOTHESIS FOR UNDERSEA MOUNTAIN RIDGES: Geology: *William Maurice Ewing* (1906–1974), United States.

The thin crust of the ocean floor enables the sea floor to spread, producing the upward movement of basalt rock and the formation of massive, long, worldwide underwater mountain ridges.

William Ewing, a geophysicist and oceanographer, employed seismic reflection technology to determine that the crust of the ocean floor is only 3 to 5 miles deep, as compared to the depth of 25 to 60 miles for the land crust. He was also aware that the Mid-Atlantic Ridge had been detected in 1865–1866 when the intercontinental communication cable was laid across the ocean floor. His theory extended the ocean ridge system to over 40,000 miles of underwater mountains worldwide. Ewing and the American geologist Bruce Charles Heezen (1924–1977) discovered the Great Global Rift, a split in one of the major submerged ranges that created a gap deeper and wider than the Grand Canyon. His theory led to the concept for the movement of continents and the six major tectonic plates, of which five support the continents while the sixth plate forms the Pacific Ocean, causing earthquakes and volcanoes to occur along the boundaries where these plates meet. Today the concepts of plate tectonics, continental drift, and midocean ridges and rifts are well-established phenomena which indicate that Earth is a dynamic planet.

EYRING'S QUANTUM THEORY OF CHEMICAL REACTION RATES: Chemistry: *Henry Eyring* (1901–1981), United States.

It is possible to determine the rate at which molecules break up and form new molecules by calculating the surfaces of the atoms and molecules involved as related to the temperature of the chemical reaction by using statistical quantum mechanics.

It had been known for many decades that the rate at which a chemical reaction takes place is dependent on temperature (as well as some other factors). This relationship can be expressed by the following formula: $k = Ae^{-E/RT}$, where k is the frequency rate of the chemical reaction, Ae is the energy involved in the reaction, and T is the temperature of the reaction.

Henry Eyring's extensive work as a creative chemist was most evident in the field of chemical kinetics as related to quantum mechanics. Based on the work of other scientists who indicated that a relationship between energy levels of molecules and their surfaces could be calculated using quantum mechanics, Eyring determined that the energy required to start a chemical reaction must be overcome to begin the reaction. The formula that explains this concept is very complex and mainly involves temperature, but other stress factors may be "plugged" into the formula that determines the rate at which a particular chemical reaction will occur.

Henry Eyring, the son of American Mormon missionaries who became Mexican citizens, was born and raised on a cattle ranch in Juarez, Mexico. During one of Mexico's many revolutions, the family was forced to cross the border to El Paso, Texas, and soon moved to Pima, Arizona, where the young Henry finished high school. He entered the College of Eastern Arizona and in 1919 received a fellowship to the University of Arizona, receiving a degree in mining engineering and chemistry. He was an affable young man with great curiosity and high intelligence who decided to work on a PhD in chemistry at the University of California, Berkeley. From 1931 to 1949 he was an instructor, and later in 1938 a professor of chemistry at Princeton University. His last appointment was as dean of the Graduate School at the University of Utah where he remained until retirement in 1966.

The Eyring theory has become known as the "Eyring model" because it can be applied in many situations involving multiple stresses. It can also be used to determine the degradation and failure date of systems, and how temperature is related to failed materials and mechanisms. One drawback of the Eyring model is that it does not directly address other stress factors. Thus, many simplified versions of the formula have been devised to address specific types of stress other than temperature.

F

FABRICIUS' THEORY OF EMBRYOLOGY: Biology: *Girolamo Fabrizio* (1537–1619), Italy.

> *The chalazae (spiral threads that suspend the yolk inside the egg) produce the chick embryo, while the sperm, yolk, and albumen of the egg merely furnish nourishment for the forming embryo.*

Although Fabricius' theory about the formation of the chick embryo was incorrect, he based his ideas on direct, but misconstrued observations. He did, somewhat accurately, describe the development of the chick embryo in the egg from the sixth day of fertilization. However, he did not realize the importance of male semen in the fertilization process or the earliest periods of embryonic development. He also studied the early developmental stages of eggs and placenta tissues of many vertebrates including mammals, reptiles, and sharks, in addition to birds and chicken embryos. His research led to the publication of two books: *De formato foetu* (On the formation of the fetus) in 1600, and *De formatione ovi et pulli* (On the development of the egg and chick) in 1612. These books contained well-drawn, descriptive illustrations based on his many observations and are considered to be the beginning of embryology as a field in the biological sciences.

As was common in the past, he had several names. *Fabricius Hieronymus* was his Latin name; *Fabrizo d'Acquapendente* is the name he was given for the town in which he was born, and his Italian name was *Geronimo Fabrizio*. Fabricius was not only a student of the great anatomist Gabriello Fallopius but he succeeded him as head professor of anatomy at the University of Padua, teaching there for fifty years. While at Padua, he built the first known anatomy theater that was used for demonstrations and the teaching of anatomy. It still exists today and continues to be used for surgical demonstrations. He was also the mentor to William Harvey, the renowned English physician and anatomist.

Some of Fabricius' research involved studies of the larynx, esophagus, respiration, muscle reactions, the stomach and intestines, the eye, and ear, all of which were done with animals rather than humans. At this time in history, dissections on human cadavers were extremely limited, often unlawful, and rare. He was the first to demonstrate the existence of "valves" within veins, although he had no idea of the function of these folds of tissue within veins. His student William Harvey followed up on this discovery and became noted for his study and description of the body's circulatory system.

Although Fabricius retired from his position at Padua after fifty years as professor of anatomy, he continued his research until he died at age eighty-six.

FAHRENHEIT'S CONCEPT OF A THERMOMETER: Physics: *Daniel Gabriel Fahrenheit* (1686–1736), Germany.

> *The temperature required to reach the boiling point for a liquid varies as to the atmospheric pressure. Thus pressure affects the temperature reading.*

Daniel Fahrenheit, glassblower and maker of scientific instruments, knew of Galileo's thermoscope, which used the change in the volume of air (density) to indicate changes in temperature (see Figure G3 under Galileo). The *thermoscope* was inaccurate because it relied on the effects of atmospheric pressure on the water encased in the instrument. The first closed water thermometer was designed in the mid-1600s by either Ferdinand II, the grand duke of Tuscany, or the astronomer Olaus Romer. Romer improved the design by using wine rather than water that provided some alcohol to prevent freezing when ambient temperatures were below the freezing point of water. These designs responded to temperature changes, but not atmospheric pressure, as did Galileo's air thermometer. Another problem was that the water and alcohol mixture still created internal pressure changes and froze and boiled at temperatures just beyond normal ranges, thus reducing its precision and usefulness.

In 1714 or 1715, Fahrenheit improved the design by enclosing mercury in a glass tube, similar to today's mercury thermometers. He also devised an improved scale by selecting one without fractional units. His design placed the mercury in a vacuum within a sealed glass tube, which eliminated the effects of atmospheric pressure, as well as normal freezing and boiling problems. Fahrenheit then combined ice and salt to determine 0° on his scale, which had each degree divided into four divisions. He then placed it in his mouth to determine human body temperature as 96°, eventually corrected to 98.6°. Later, his thermometer and scale were calibrated to establish 212° as the boiling point and 32° as freezing of water at sea level. The Fahrenheit scale is used only in English-speaking countries, particularly the United States. Scientists worldwide use the more appropriate metric Celsius and Kelvin scales.

See also Celsius; Kelvin

FAIRBANK'S QUARK THEORY: Astronomy: *William Fairbank* (1917–1989), United States.

> *Quarks originate from high-energy cosmic rays. Therefore, their electrical charge can be detected and measured.*

In 1964, Murray Gell-Mann, a particle physicist, postulated the existence of **quarks** that are strange, basic, subnuclear particles composed of protons and neutrons. Each had an *antiquark* and needed fractional electrical charges of either −1/3 or +2/3 to produce other particles. Also, they were thought to be not artificially producible because they were beyond the energy range of particle accelerators.

In 1977, using a sensitive device similar to the Millikan oil drop experiment (*see* Millikan), Fairbank determined the electric charge of an electron. He placed a tiny ball of the element niobium (about 0.25 mm in diameter) between two charged metal plates that were kept at a temperature near absolute zero. As a cosmic ray passed through this device, a small electrical charge formed on the ball, which could be measured as a change in the electrical field between the plates. The strength of the charge was extremely small (−0.37) and may have been caused by sources other than cosmic rays. There is one theory that says quarks cannot be produced because they are not "free." The question of magnitude of the charge on a quark is still being investigated. Twelve different types of quarks have been discovered, and now physicists believe the quarks in protons and neutrons are "confined" or held together by the "strong force" of gluons.

See also Friedman; Gell-Mann; Glashow; Nambu

FAJANS' RULES FOR CHEMICAL BONDING: Chemistry: *Kasimir Fajans* (1887–1975), Poland and United States.

Rule #1: *When the number of electrons increases for an atom, its ions obtain a higher charge and thus are difficult to form. Therefore, they are more likely to form covalent bonds rather than ionic bonds.*

Rule #2: *Large cations are more likely to form ionic bonds with smaller anions rather than covalent bonds.*

These two rules apply to the similarity of elements that are close neighbors on the Periodic Table of Chemical Elements. The rules explain the difficulty and the ease with which atoms gain or lose electrons, as the atoms become ions. It is almost impossible to form large highly charged ions. Therefore, covalent (sharing) bonds with another ion are more likely as the number of electrons to be removed or donated increases. Conversely, ionic bonds are more likely to form as the number of electrons to be removed or donated from large atoms becomes greater. This results in the rarity of highly charged ions. The second rule is more self-evident in that it states that ionic valences are more likely to form between large cations (positively charged ions or radicals that are attracted to the positive "anode" in electrolysis); and small anions (negatively charged ions or radicals that are attracted to the positive "cathode" in electrolysis). Two examples evident on the Periodic Table are the Earth metals located in the upper left-hand area of the table, namely 1) Groups I and II [Lithium (Li), Beryllium (Be), and Magnesium (Mg)] and 2) Groups III and IV [Boron (B), Aluminum (Al), and Silicon (Si)].

Fajans' law that was conceived in 1913 states that elements that emit alpha particles (positive helium nuclei) will decrease in their atomic numbers (and weights) and thus become positive ions as well as isotopes, whereas elements that emit beta rays (high-speed negative electrons) will gain electrons and thus become negative ions. He also formulated the law explaining how radioactivity moves. This law explained valence in chemical bonding and was later independently discovered by the British chemist

Kasimir Fajans was born in Warsaw, Poland, and educated at several institutions located in Heidelberg, Zurich, and Manchester, England. He emigrated to the United States in 1936 to serve as professor of chemistry at the University of Michigan. Fajans' experience with the Nobel Prize Committee is an example of the fickleness in which that institution occasionally operates. In 1924 Fajans was a candidate for the Nobel Prize in Chemistry and Physics and was expected to be a "winner" by all concerned. Even a Swedish magazine asked Fajans for a photograph to be used with the announcement of his award. On the day before the winners were announced, the magazine had already published an article that Fajans had won the prize. The next day the Committee changed its mind and announced there would be no winner in this category for 1924, ostensibly because the Committee wanted to chastise the magazine for its indiscretion in printing the article. In future years Fajans was again a candidate several times but never did win a Nobel Prize even though Frederick Soddy did receive the Nobel Prize for Chemistry and Physics in 1921 for his research related to Fajans' discoveries related to radioisotopes. In future years, Fajans received many awards from other institutions and academies.

Frederick Soddy. It became known as the Soddy–Fajans Method. In cooperation with Otto Göhring (1879–1968), Fajans discovered the radionuclide of the new element protactinium in 1913. Fajans and Göhring also jointly discovered the formula that defined the conditions for the precipitation of radioactive materials that could be used to separate small amounts of radioactive substances.

FALLOPIUS' THEORIES OF ANATOMY: Biology (Anatomy): *Gabriel Fallopius* (1523–1562), Italy. In Italian, his name was Gabriele Fallopio of Modena.

The female reproductive anatomy includes the ovaries that connect into "trumpet" (tuba) shaped tubes leading to the uterus.

The detailed anatomical examinations of the female reproductive organs that were done by Fallopius led to better understanding of how this system functions. The "tubes" through which the eggs pass became known as the "fallopian" tubes. Although Fallopius did not understand exactly the functions of these organs, he did realize that they were related to the reproductive process. He was also the first person to describe in detail the clitoris, and he coined the term "vagina" which he knew received the sperm from males during copulation. He was the first person to record experimental tests of different type sheaths made of linen and parchments designed to fit over the penis that could prevent syphilis during sexual intercourse. One might say he was the first to scientifically conduct research of the efficacy of condoms. His main concern was not contraception but rather the prevention of disease. Several hundred years would pass before it became known and understood how ova (eggs) form in the ovaries and pass through the fallopian tubes to the uterus to become an embryo and develop into a fetus. There are many specific parts of the female reproductive anatomy that have acquired his name, such as, fallopian aqueduct, fallopian canal, fallopian arch, fallopian ligament, fallopian neuritis, fallopian pregnancy, aqueducts fallopii, and tuba fallopiana.

Gabriel Fallopius became a greater anatomist than his famous teacher, Andreas Vesalius, the famous Belgian anatomist. Fallopius' writings explain his work with the skull and, in particular, the ear and auditory system. Fallopius introduced the terms "cochlea" and "labyrinth." He also described the larynx, respiration, and how muscles perform within the body.

FARADAY'S LAWS AND PRINCIPLES: Physics: *Michael Faraday* (1791–1867), England.

Faraday's laws of electrolysis: *1) equal amounts of electricity will produce equal amounts of chemical decomposition* and *2) when using an electric current, the quantities of different substances deposited on an electrode are proportional to their equivalent weights*.

Michael Faraday, who was Sir Humphry Davy's laboratory assistant, continued Davy's work on the electrolysis of chemical substances by passing electricity through chemical solutions. Davy demonstrated that sodium and potassium metals were deposited on the two electrodes in a solution of sodium chloride and potassium chloride (both salts) through which an electric current was passed (see Figure A7 under Arrhenius). Faraday went one step further and measured the amount of electric current being used and its effect on the deposition of either the sodium or potassium on one or both electrodes. His hypothesis was that the chemical action of a current is constant for a proportional amount of electricity. The equivalent weight of a chemical is the *gram formula weight*—the sum of the atomic weights of the elements as expressed in the formula, related to a gain or loss of electricity (electrons). The amount of electricity required to cause a chemical change of one equivalent weight is the unit named a *faraday*. The faraday constant is equivalent to 9.6485309×10^4 coulombs of electricity. Faraday's laws of electrolysis have been used over the past one hundred years to produce all kinds of chemicals. For example, electrolysis can be used to produce hydrogen and oxygen gases by breaking down water molecules in a weak electrolytic solution. No relationship exists between Faraday's laws of electrolysis and the cosmetic process of electrolysis for hair removal.

Faraday's principle of induction: *An electric current can produce a magnetic field; conversely, a magnetic field can produce an electric current*.

Oersted and Ampère had previously demonstrated that when electric current flows through a wire placed over a compass, the magnetic needle of a compass is deflected. Faraday rejected the then-current belief that electricity was a fluid, and with great insight, he saw electricity as one of several "uniting forces of nature," which he included with magnetism, heat, light, and chemical reactions.

Faraday recognized a connection between the actions of electrical lines of force and the magnetic lines of force. He devised an iron ring with a few turns of wire wrapped around opposite sides of the ring. The wires did not touch each other because he used twine to keep them separated. First, he connected a battery to the two ends of the wire on one side and a **galvanometer** to the two ends of the wire on the other side. When the electrical connection was made on the side with the battery, the needle on the galvanometer on the other side of the iron ring moved. Next, he tried the same experiment without the electric battery by passing a bar magnet through a ring that had a coil of wire wrapped around it. Again, the needle of the galvanometer moved when attached to the ends of this coil. His interpretation was that lines of "tension," as he called the lines of force of the magnetic field, created an

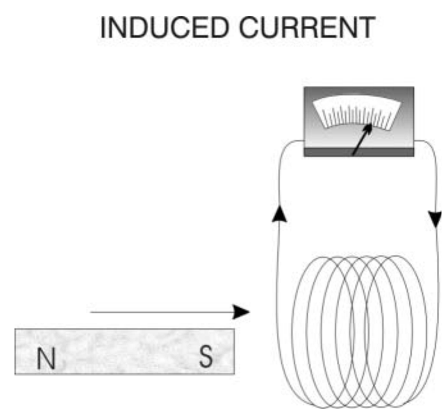


Figure F1. When the magnet is moved into and out of a coiled wire, an electric current is "induced" in the coil by the influence of the moving magnetic field. This is known as the *dynamo effect.*

electric current as the magnet moved through the ring (coil) of wire. Thus, an electric current was "induced" in the wire by the moving magnet (see Figure F1).

Faraday was not an accomplished mathematician. Others, particularly James Clerk Maxwell, developed the mathematics required to make Faraday's concept of induction into a viable field theory. By all and any scientific landmarks, recognizing electromagnetic induction was one of the most important human insights. The concept of induction resulted in the development of the dynamo, or electric generator, which produces electricity by mechanical means, and thus led to the modern age of electricity. Induction (brushless) electric motors have many modern applications, including the small induction motors that run the hard drives of personal computers (*see also* Edison; Henry; Tesla).

Faraday's principle of dielectrics: *The conductivity of different substances has different specific inductive capacities for the dissipation of electrical power.*

The *inductive capacity* refers to how much *permeability* and *permittivity* a substance exhibits; the *dissipation* of electrical power is the rate of heat loss within the system. This principle states that some substances are very poor conductors of electricity and that induction of electricity relates to the "dielectric" nature (the degree of insulating properties) of the substance. The dielectric strength (permittivity) of a substance is related to how much electricity can be passed through it without breaking down the material. Being able to calculate the dielectric nature of a substance is very important for many industrial uses, including the manufacturing of semiconductor computer chips. As an example, materials with high dielectric constants make excellent **capacitors**, which are important in the electronics industry because they can be made very small and still do the job. Knowing the dielectric properties of substances becomes important when looking for material suitable to make insulators, capacitors, and microelectronic components.

Faraday rotation effect: *The plane of polarization of polarized light will be rotated when passed through a magnetic field.*

Faraday's work with electricity and magnetism led him to explore relationships between light and magnetism. He demonstrated that polarized light can be altered when influenced by magnetic fields of force. This *Faraday effect* was developed for instruments used to study the molecular structures of many compounds and later was useful in explaining magnetic fields in the other galaxies of the universe. Faraday's other contributions include the discovery of benzene (C_6H_6) and two new chlorides

Michael Faraday was an excellent thinker and experimenter with the ability to relate his abstract ideas into understandable presentations for his audiences during his famous lectures. His most famous were his popular seasonal Christmas-time lectures for children that he began in 1826; the tradition has been continued ever since and attracts a full audience of young people.

As a young scientist, Michael Faraday was basically a theoretical and experimental chemist. When he was twenty-nine years of age, he synthesized several new chlorine compounds C_2Cl_6 and C_2Cl_4, and several years later he discovered benzene C_6H_6. However, the shape of the benzene molecule eluded him (the "ring" shape of the benzene molecule was later discovered by Fredrich Kekule; *see* Figure K1 under Kekule). Faraday's concepts related to electrolysis were based on his ability to theorize the process of electrolysis, but he also used experimental research to measure chemical and physical changes on the electrodes (cathode and anode). An important concept of electricity is related to how much is required to liberate one mole of individually charged ions. This led to what is known as the *Faraday constant* which is expressed as: $F = N_A{}^e$, where F is the Faraday constant, N_A is the Avogadro constant, and $^{e-}$ is the electrical charge on a single electron.

of carbon, as well as the system for liquefying several common gases, including chlorine.

See also Ampère; Maxwell; Oersted

FERMAT'S PRINCIPLES AND THEORIES: Mathematics: *Pierre de Fermat* (1601–1665), France.

Fermat's combination theory: *Combinations of units are based on the concept of probability.*

Pierre de Fermat and Blaise Pascal are credited with developing theories of probability. *Probability* is the ratio of how many times an event will occur as related to the total number of trials conducted.

A famous example of Fermat's theory of combinations follows. In a game where there are just two players, player Allen (A) and player Bill (B), player A wants at least 2 *A*'s or more in a combination of four letters to "win" a point, while player B wants at least 3 or more *B*'s in a four-letter combination to gain points (Because 3 is greater than 2, Bill felt this higher number would win more combinations). There are 16 possible combinations for these two letters: *AAAA, AAAB, AABA, AABB, ABAA, ABAB, ABBA, ABBB, BAAA, BAAB, BABA, BABB, BBAA, BBAB, BBBA, and BBBB*. Every time an *A* appears at least two times or more in a combination, Allen will score a point. At the same time, player Bill requires *B* to appear at least three times or more within a combination to win a point. Note that there are eleven "wins" based on two or more *A* appearances within the sixteen combinations for player A; while there are only five cases containing at least three or more *B* appearances within the sixteen combinations for player B. The odds for Allen (A) winning the game over Bill (B) are eleven to five. Also, it is most likely (statistically probable) that A would win the game after only four random selections of combinations.

Fermat's last theorem: *For the algebraic analog of Pythagoras' theorem for a right triangle, there is no whole number solution for the equation* $a^n + b^n = c^n$ *(e.g.,* $3^2 + 4^2 = 5^2$; *or* $9 + 16 = 25$*) for a power greater than 2.*

Integers are positive or negative whole numbers that have no fractional or decimal components and can be counted, added, subtracted, and so forth. Pythagoras' theorem states that the square of the length of the **hypotenuse** in a right triangle is equal to the sum of the squares of the lengths of the other two sides of the triangle (see Pythagoras).

Although Fermat had an interest in the theory of numbers, as well as making several contributions to this field, Fermat's record keeping was poor. The equation for the "last

Pierre de Fermat did not publish much of his work during his productive years. Although a few fellow mathematicians knew about his ideas, his most important work did not become known until after his death. Proof of his "last theorem," also known as the "great theorem," obtained a reputation of insolvability that has intrigued amateur as well as professional mathematicians for ages. In the early 1900s over one thousand proofs were presented for his theorem; all were proven incorrect. After computers became available for number "crunching," an English mathematician Andrew Wiles (1953–) presented a proof that looked promising. Unfortunately, his proof had some problems that were finally worked out with assistance from a mathematician from Cambridge, England. Finally, in 1995 Wiles derived a version of the proof for Fermat's last theorem that seems to be correct. Wiles does not believe that Fermat had a secret "proof" that, for unknown reasons, he chose not to have published. Rather, at that time in history, neither the knowledge nor tools to solve the problem were available.

theorem" was written as: $a^n + b^n = c^n$ (or as $x^n + y^n = z^n$), and if the *n* is an integer greater than 2, there is no whole number solution. Fermat professed to have solved this problem, but his solution has not yet been found. For almost four hundred years, scholars have attempted to solve this mathematical conundrum. It seems that when *n* is 2, it is possible to express the value for *a*, *b*, or *c*, but once whole numbers greater than 2 are used for *n*, it cannot be calculated. Some claim to have arrived at a proof for $n = 3$, $n = 4$, $n = 5$, and $n = 7$, or even $n = 14$, but only when using prime and complex numbers.

Fermat's least time principle for light: *Electromagnetic waves (light) will always follow the path that requires the least time when traveling between two points. In addition, light will travel slower through a dense medium than one less dense.*

Fermat related light to mechanics in the sense that light followed mechanical principles, such as expressed in geometry and the physics of his day. For instance, the *principle of least action*, originally postulated by Aristotle as the *economy of nature*, was also used by Fermat to describe the behavior of light under different circumstances. He based his theory on analytical geometry, which showed that the path of light reflected from a flat surface always took the shortest distance, but for an elliptically curved surface, it took the longest path. Fermat's theory was later restated as the *wave theory of light* during the period when the principle of least action was applied to wave mechanics and quantum mechanics.

See also De Broglie; Descartes; Hamilton; Schrödinger

FERMI'S NUCLEAR THEORIES: Physics: *Enrico Fermi* (1901–1954), United States. Enrico Fermi was awarded the 1938 Nobel Prize for physics.

Fermi's theory for slow neutrons: *Since slow neutrons have no charge and less mass than alpha particles, they are capable of overcoming the positive charge on atomic nuclei, thus allowing them to enter (react with) the atomic nuclei to increase their atomic weight but not their charge, thus producing isotopes.*

Neutrons are found in the nuclei of atoms and have approximately the same atomic weight as protons but no electrical charges. Both protons (with +1 charge) and neutrons (with 0 charge) belong to the group of particles known as "baryons" that consist of quarks (*see* Gell-Mann). Neutral neutrons can be stripped from certain types of nuclei and used as particles to combine with other target nuclei, thus increasing the atomic weight and instability of the target nuclei. Alpha particles are the nuclei of helium atoms composed of two positive protons (++He). Thus, an alpha particle is approximately twice the weight of a single neutron. An isotope of an element whose atomic nucleus is composed of a specific number of protons is also defined by the number of neutrons in the nuceli. Thus, isotopes of an element have the same atomic number (protons) but different numbers of neutrons, thus different atomic weights.

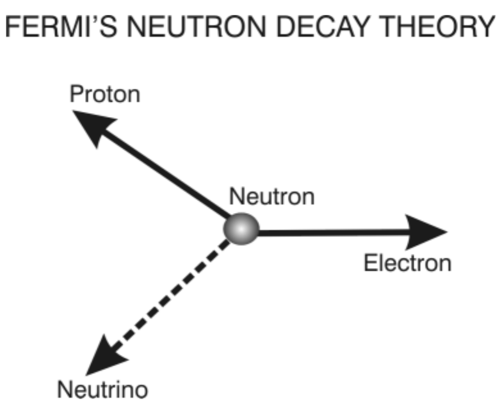


Figure F2. Enrico Fermi predicted that when a neutron disintegrated, the products formed were a proton, an electron, and a very small unknown particle with less than 1 percent the mass of an electron, or possibly no mass at all. This new particle was named the neutrino ("the little one") that became known as the "ghost" particles. In 1956, Frederick Reines and Clyde Cowan confirmed the existence of the neutrino.

Enrico Fermi considered using the neutron as the "bullet" to bombard atomic nuclei to produce isotopes since it has no charge and therefore little resistance to target elements. At that time he could not produce adequate numbers of neutrons for this action. On a hunch, he placed a thin sheet of paraffin (petroleum wax) between the neutron source and the target. To his astonishment, the production of neutrons increased about 100-fold because they were being slowed by the hydrocarbon molecules in the paraffin, and thus were more easily detected. Because more neutrons were produced and, more important, were slowed down, they would not "bounce" off the target nuclei, as did high-speed neutrons. Thus, it provided a better opportunity for the neutrons to interact with the nuclei of the target and produce isotopes of that element by adding neutrons to the target element's nuclei, thus increasing the element's atomic weight as well as creating an isotope of that element.

Fermi used his new technique to produce numerous radioisotopes of several elements. His theory of slow neutrons was of extreme importance to the new field of nuclear science, which soon led to the nuclear bomb, production of electricity by nuclear power plants, and the production of radioisotopes used in industry and medicine.

Fermi's theory of beta decay: *When a neutron decays, it is converted into a positive proton plus a negative electron and an antineutrino.*

The equation for this reaction is: ($n \rightarrow p + e^- + v$) where *n* is the neutron; *p* is the proton, *e* an electron, and *v* the **antineutrino** (see Figure F2).

This reaction led Fermi to speculate on a new force he named the "weak force" or "weak interaction," which is responsible for the beta decay process of the neutron. Beta decay occurs when the nucleus emits or absorbs an electron or positron, either increasing or decreasing the element's atomic number but not its atomic weight. The beta decay phenomenon resulted in additional research and discoveries related to the structure of the nuclei and radioactivity.

Fermi's theory for a self-sustaining chain reaction: *A self-sustaining chain reaction can be produced by stacking uranium oxide (uraninite ore) and graphite blocks (carbon as a moderator) into an ''atomic pile'' to produce slow neutrons that will interact with the small amount of fissionable uranium-235 (U-235) in the refined ore.*

After the discovery of the neutron in 1932, a number of scientists began to work with nuclei, neutrons, other elementary particles, and nuclear fission reactions. Familiar with this

On December 6, 1941 (one day before the bombing of Pearl Harbor by the Japanese), this ultra-secret Manhattan Project was tasked with demonstrating that a self-sustaining chain reaction was possible and could be used to convert a small mass of uranium into tremendous amounts of energy, as theorized by Einstein's famous equation, $E = mc^2$. For this purpose, an atomic pile was constructed beneath the stands at the University of Chicago's football stadium. It was designed to slow the neutrons to the extent they would produce adequate fission of the nuclei, which at some unknown point would enable the reaction to sustain itself. The pile was extra large to determine the amount of U-235 needed to reach a **critical mass**, resulting in fission of the U-235. The scientists had one problem. If this critical mass was reached, what would prevent the pile from becoming an exploding bomb? To solve this problem, Fermi and his colleagues devised a means of inserting cadmium rods into the pile to absorb the neutrons before the whole thing became unstable. As the rods were slowly removed, the number of slow neutrons needed to react with the U-235 could be controlled. There were also so-called delayed neutrons produced that kept the pile from going out of control by providing a brief period of safety before the rods needed to be reinserted. This happened on December 2, 1942. Then the neutron-absorbing rods were reinserted, and history was made.

science, Fermi was charged with the supervision of the Manhattan Project that was composed of a group of physicists attached to various universities. They became volunteer consultants who advised the U.S. government on the Manhattan Project and on the development of the atomic bomb and other classified military projects.

Today we know it takes only about 15 pounds of the rare form of U-235 to reach a critical mass, and less than 10 pounds of fissionable plutonium Pu-239 is required to form a self-sustaining chain reaction, and thus an explosive device. Enrico Fermi went on to assist other scientists with the construction of the atomic (nuclear fission) bomb and the H-bomb (thermonuclear fusion bomb).

See also Hahn; Meitner; Pauli; Oppenheimer; Steinberger; Szilard; Teller

FESSENDEN'S CONCEPT OF THE THERMIONIC DIODE: Physics: *Reginald Aubrey Fessenden* (1866–1932), Canada.

The heated negative cathode and the positive cool anode that make up a diode can accommodate a third electrode between them to form a triode. The third electrode can be used to modulate the amplitude of a wireless carrier signal.

The concept of thermionic emission within diodes was referred to as "tubes" in the United States and "valves" in England. The word "diode" is derived from the word di-electrode meaning two electrodes. The di-electric vacuum tube rectifier was first invented by the English electrical engineer and physicist Sir John Ambrose Fleming (1849–1945) in 1904. In essence, when the negatively charged metal cathode electrode inside a vacuum tube is heated and the positively charged anode is kept cool, the electrons that are "boiled" off the cathode form a cloud of electrons around the heated cathode that are attracted to the anode. This "boiling off" of electrons is called the "thermionic emission" because the electrons from the metal electrode are produced by the heat.

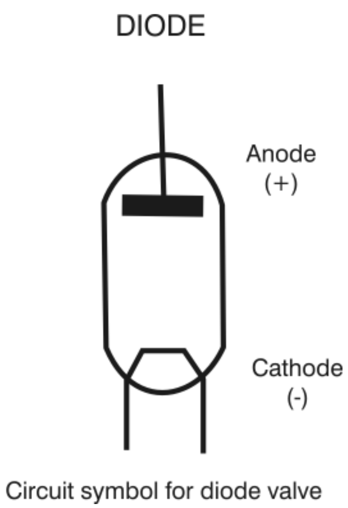


Figure F3. An artist's depiction of a simple diode.

Reginald Fessenden inserted a third electrode that could vary the flow of electrons from cathode to anode and thus vary the amplitude of a steady high-frequency radio signal. Thus the frequencies of sound waves could be modulated to correspond with the frequencies transmitted over the radio waves. This third electrode in the triode made it possible to modulate the flow of electrons from the cathode to the anode so the signal could act as a "carrier wave" for audio (sound) transmissions.

From early childhood Fessenden was interested in the possibility of a wireless telegraph and eventually developed an oscillating triode system that was the basis for his first successful self-sustaining wireless system that was a two-way (sending and receiving) system. On Christmas Eve in 1906 he transmitted the first historic audio radio broadcast from Brant Rock, Massachusetts. Reginald Fessenden was somewhat of a child prodigy and as a youngster became interested in how to send Morse code without the use of wires. He also witnessed a demonstration of Alexander Graham Bell's invention, the telephone. After training as an electrician, Fessenden worked with Thomas Edison in an attempt to find better insulations for electrical wires. He was a professor of electrical engineering at several universities, worked for the U.S. Weather Bureau, and tried to exploit his own inventions without much success. Fessenden formed the National Electric Signaling Company (NESCO) with two businessmen that provided him an opportunity to continue his research and the development of devices for wireless transmission of sound. A lifelong impediment to a more widespread recognition of his accomplishments was his personality that did not lend itself to compatibility. He had a fear, some say, of being "robbed" of his ideas and inventions. Eventually, his backers at NESCO fired him. Fessenden sued them and was awarded over $400,000 that resulted in the company's bankruptcy. Fessenden had many ideas and was a prolific inventor with over five hundred patents in his name.

See also Edison; Esaki; Tesla

FEYNMAN'S THEORY OF QUANTUM ELECTRODYNAMICS (QED): Physics: *Richard Phillips Feynman* (1918–1988), United States. Richard Feynman, Julian Schwinger, and Sin-Itiro Tomonaga shared the 1965 Nobel Prize for Physics.

> *Quantum electrodynamics joins three seemingly unrelated physical phenomena: Einstein's concepts of relativity and gravity, Planck's quantum theory, and Maxwell's electromagnetism.*

This theory is also known as the quantum theory of light, which synthesizes the wave and particle nature of light with the interaction of radiation and electrically charged particles.

Richard Feynman's theory grew out of the problem presented with the interactions between electrons and photons of light in which the strength of the charge on the electron mathematically came out to zero, while in actuality the basic unit of electricity is the electron. This did not coincide with known properties of electrons, so a new approach was required. Feynman's concept was based on the probability that if something does happen, it can also happen in many different ways. Thus, the probability of locating an electron in any particular space is like saying it would be in all the places it probably could be. To assist in understanding his version of the quantum theory, he designed what are known as "Feynman diagrams," which are simple sketches, similar to vector diagrams, that can be used to trace and calculate the paths of subatomic particles generated in nuclear bombardments that produce new particles and radiation.

> In addition to being a creative and excellent scientist, Richard Feynman was adept in explaining advanced physics concepts to the nonscience public. He presented many popular lectures which were published in 1963 as *Feynman Lectures on Physics.* Later in 1985 he presented a series of TV lectures followed by a book titled *Surely You're Joking Mr. Feynman.* This book made him a celebrity. He believed that science is not an impersonal enterprise, but rather follows rules, procedures, processes, and experimental tests—it is the results of these tests that are the science—not the individual involved. Even so, science is a rather recent human activity designed to explore the nature of the entire universe. He also was interested in and worked on other problems of physics besides the strong nuclear interaction. He explored superconductivity that led to a new model for the structure of liquid helium.

At the age of twenty-four, Richard Feynman was the youngest scientist to work on the atomic bomb project during World War II. One of his main contributions took the form of four questions he proposed to the senior scientists on the project for which answers were needed to make the goals of the project achievable: 1) How much fissionable material is needed to achieve a critical mass? 2) What type of material would best make a reflector, or "lens," to focus neutrons on the uranium? 3) How pure must the uranium be? 4) What would be the expected extent of the damage the explosion would cause (by heat, shock waves, and radiation)? His questions focused the direction of the project and saved time and money in designing the final A-bombs.

See also Bethe; Fermi; Oppenheimer; Teller; Ulam

FIBONACCI'S NUMBERING SYSTEM: Mathematics: *Leonardo Fibonacci* (c.1170–1250), Italy. (Fibonacci was a nickname. His real name was Leonardo Pisano, and he also went by the name Bigollo.)

Fibonacci was one of Leonardo Pisano's nicknames, albeit his most famous one. Pisano called himself Fibonacci, short for *fillio Bonacci* ("Bonaccio's son"). His father's name was Guglielmo Bonaccio, also a nickname, meaning a "good, stupid fellow." Leonardo was also known as *Bigollo* which comes from the Italian word *bighellone* meaning "loafer" or "wanderer."

The "Fibonacci sequence" of numbers was based on the breeding of rabbits. If each pair of rabbits gives birth to another pair, and in one month this pair gives birth to another pair, and this pair gives birth to another pair in one month, and so on, and so on, and they are all alive after a reasonable time, the number sequence would look as follows:

F_n represents the Fibonacci numbers
$F_0 = 0$
$F_1 = F_2 = 1$
$F_n = F_{n-1} + F_{n-2}$
$F_{(-n)} = (-1)^{n-1} \bullet F_n$

The Fibonacci numbers are easier to understand when expressed as a series of numbers in which each successive number is the sum of the preceding two numbers, such as: $1 + 1 = 2$; $1 + 2 = 3$; $2 + 3 = 5$; $3 + 5 = 8$; $5 + 8 = 13$; $8 + 13 = 21$; $13 + 21 = 34$; etc. This way of calculating Fibonacci numbers for the sequential birth of rabbits can be depicted in a visual graph that shows the exponential nature of the sequence. This problem was first published in 1202 along with several other books that introduced solutions to problems in mathematics. Fibonnacci is credited with introducing the Hindu/Arabic decimal numbering system to Europe (1 to 9 plus 0). Up to this time calculations in European countries were accomplished with Roman numerals, which by any standard are difficult to use even in solving simple problems in arithmetic. He most likely learned the Arabic/Hindu numbering system as he traveled widely over the Byzantine Empire with his father who was a customs officer and merchant. Fibonacci spent the rest of his life studying mathematics and writing several important books, including *Liber abbaci* (1202, 1228); *Practica geometriae* (1220/1221); *Flos* (1225); and *Liber quadratorum* (1225). Because this was before the invention of the printing press, his books had to be copied by hand, which makes it unusual that some of these original volumes still exist.

An interesting mathematical property of the Fibonacci sequence of numbers is the ratio between the numbers, that is, 1/1; 2/1; 3/2; 5/3, and so on (by dividing the first number by the second. Two examples: 5 divided by 3 = 1.666; or 25 ÷ 13 = 1.615), which as the sequence increases the ratio become close to the number 1.618 that is known as the *golden ratio*.

The golden ratio is defined as an irrational number that is approximately 1.618. It is the ratio of a diagonal of a pentagon to its side and appears in numerous metrical properties of 12- and 20-sided polygons, just as the square root of 2 appears in the metrical properties of a 6-sided square or cube. Euclid included the first calculation of the golden ratio in his book *Elements* written in about 300 BCE. The golden ratio essentially defines the balance between symmetry and asymmetry in various shapes in nature and is used in art design, as well as in psychology, metaphysics, and history to represent those forms that are aesthetically pleasing, particularly in Western culture.

There are a number of examples in nature where this ratio is exhibited, for example, petals on flowers, seeds on sunflowers, and the ratio of your height to the distance from your belly button to the ground. It is also found in areas of science including symmetry as a constant in physical laws (e.g., cosmology). Admirers of Fibonacci and his mathematics founded a society in 1962 that publishes *The Fibonacci Quarterly* that seeks solutions to mathematical problems using Fibonacci's methods.

See also Euclid; Fermat; Riemann

FICK'S LAWS OF DIFFUSION: Physics and Physiology: *Adolf Eugen Fick* (1829–1901), Germany.

Fick's first law of diffusion: *The flux (J) of a fluid with the concentration (C) across a membrane is proportional to the concentration differential across the plane of the membrane. (Note: flux is the rate of flow across a given area perpendicular to the flow.)*

Diffusion is really the intermingling of a number of particles of a substance (or units of electromagnetic radiation). Diffusion may be thought of as a mechanism by which individual types of particles in a mixture are moved within the mixture by means of random molecular movement known as the *Brownian motion* (*see* Einstein). On the other hand, permeability is the ability of a substance to pass through a body based on its diffusion coefficient (D) as well as its solubility coefficient.

If there is no volume change on either side of a barrier plane, the rates of diffusion are equal and opposite. For high-density substances across a fixed barrier, the rate of diffusion is low and thus only one equation is needed. The equation for Fick's first law of diffusion can be expressed in various forms. One of the easiest to understand follows:

$J_x = -D\ dC/dx$: *where* J_x *is the flux of the two types of diffusing fluids, and* $-D$ *is a proportional constant or diffusion coefficient, and* dC/dx *equals the changes in the concentration in relation to the distance between the fluids.*

Fick's second law of diffusion: *The rate of change of the concentrations and volumes of a membrane in the diffusion field is expressed as t for the time involved in the exchange.*

The temperature or kinetic energy factor greatly influences the rate for the entire diffusion process as an increase in temperatures results in a "speeding up" of the molecular motion within the different types of diffusing substances.

Fick introduced the law of diffusion as a way to understand how gas is diffused across a fluid membrane that he used in 1870 to measure cardiac output. Since then, the equations for Fick's law have been adapted to measure the transport process of foods, polymers, pharmaceuticals, and as a means of controlling the "doping" of semiconductors to increase their efficiency.

Fick is also credited with making and using the first contact eye lens in 1887. He made an *afocal scleral* contact shell-shaped lens made of heavy brown glass that he first tested on rabbits. He then wore a pair of lenses himself before finally using his new invention on a group of volunteers.

FISCHER'S PROJECTION FORMULAS: Chemistry: *Emil Hermann Fischer* (1852–1919), Germany. Emil Fischer was awarded the 1902 Nobel Prize for Chemistry.

Projection formulas can be used to describe the spatial relationships of atoms in large organic molecules that have the same structural formula.

Emil Fischer demonstrated he could separate and identify sugars, such as glucose, mannose, and fructose, having the same empirical formula. In other words, once he determined the molecular structural formula for one type of organic substance, he could then project this information to synthesize other similar large organic molecules. In addition to his work with carbohydrates (sugars), he contributed to the understanding of the structures of purines, peptides, proteins, and caffeine alkaloids. Fischer used this theory to synthesize polypeptides that contained 18 amino acids. He also devised the "lock and key" explanation for high-molecular-weight compounds such as enzymes. Because Fischer did comprehensive groundbreaking work in the fields of purines, sugars, and peptides, which are the basis for biochemistry, he became known as the father of biochemistry. In 1882, based on his knowledge of structural formula for various organic compounds, he synthesized a number of important substances including several types of sugars.

> Emil Fischer was somewhat of a child prodigy who excelled in school to the extent that he did not need to take the school's exit examination. Afterwards, because he was too young to enter the university, he worked for his uncle in the timber industry. His father was a "jolly" fellow who ran the family grocery store, spinning mill, and brewery, and it seems Emil took after his father's personality. His family thought Emil was not smart enough to be a businessman so they assumed he should just be a student. Emil set up his own chemistry laboratory where he worked during the day. In the evenings he played the piano and drank excessively. He, in essence, was self-taught in organic chemistry and performed important research in purines, sugars, dyes, and indoles (crystallized perfume compounds). Some of his chemicals caused terrible odors that were imbedded in his clothes that made him repulsive to people. He continued to smoke and drink to the point where he had to take time off each year to recuperate. He later became a professor in Berlin, which interfered with his research. After twelve years he returned to his research that led to the second Nobel Prize awarded in chemistry in 1902.

FITZGERALD'S CONCEPT OF ELECTROMAGNETIC CONTRACTION: Physics: *George Francis Fitzgerald* (1851–1901), Ireland.

When the light from a body is moving relative to an observer's position, the light contracts slightly in the direction of the observer's motion.

George Fitzgerald and Hendrik Lorentz independently concluded that a fast-moving body appears to contract according to its velocity as measured by an instrument (or observer). This effect, known as the

Lorentz–Fitzgerald contraction, described the effect the "**ether**" (in space) had on the electromagnetic (light) forces binding atoms together. Fitzgerald's research was concerned with the study and understanding of electromagnetism based on James Clerk Maxwell's equations, as well as the existence of radio waves as predicted by Heinrich Hertz. The Lorentz–Fitzgerald contraction theory proposed to explain the observations made by Albert Michelson and Edward Morley that the speed of light did not depend on the motion of the detector. Therefore, this idea could not be used to determine the speed of movement of Earth through space. The Lorentz–Fitzgerald contraction was an opposite and alternate explanation to Einstein's theory of relativity. Einstein used this altered version of the "contraction of light" concept in developing his special theory of relativity. His theory accepted the concept of space as a vacuum; as such, matter, even "ether" could not exist in space. The concept differs somewhat from the classical Doppler effect and the redshift.

See also Doppler; Einstein; Fizeau; Maxwell; Schmidt

FIZEAU'S THEORY OF THE NATURE OF LIGHT AS A WAVE: Physics: *Armand Hippolyte Louis Fizeau* (1819–1896), France.

If the speed of light is known, it can be demonstrated that light travels faster in air than in water or substances denser than air.

Armand Fizeau was the first to measure the speed of light using something other than subjective observations or astronomy. After constructing a device consisting of a rotating disk into which two "teeth" or gaps were cut, he set up a mirror on one hill to return the light sent from another hill about 5 miles distant upon which the "toothed disk" instrument was placed. He sent a light through the gaps in the disk, which acted like a rapid on-off switch that dissected the light into small "bits," similar to a series of light dots. As Fizeau increased the speed of the rotating disk, the reflected light from the mirror on the other hill was blocked off by the solid portion of the disk, but some light would shine through the toothed gap. The faster the disk rotated, the dimmer the light became, until it was blocked entirely by the solid parts of the slotted disk. Conversely, as he slowed the disk, the light would again brighten. By measuring the speed of rotation and the brightness of the light coming through the disk and knowing the distance between the two hills, he calculated the speed of light in air (*see* Figure M5 under Michelson). Fizeau and Jean Foucault are credited with proving that light behaves as waves. With an improved instrument, they measured the speed of light in water and compared it with the speed of light in air to confirm that light travels more slowly in denser mediums (*see* Figure F5 under Foucault). Fizeau also used his instrument to determine that the Doppler effect is the change in the wavelength of light relative to speed. This is known as the *Doppler–Fizeau shift*.

See also Doppler; Einstein; Fitzgerald; Foucault; Maxwell; Michelson; Schmidt

FLEISCHMANN'S THEORY FOR COLD FUSION: Chemistry: *Martin Fleischmann* (1927–), England.

Nuclear fusion can be achieved at room temperatures by the process of electrolysis using palladium as an electrode in an electrolyte of heavy water.

In 1989 while at the University of Utah Martin Fleischmann and the American electrochemist Stanley Pons (1943–) announced they had sustained a controlled fusion reaction in a laboratory setting at room temperatures that produced 100% more energy than was used by the electrolytic process. If this proved to be possible, it was estimated that the discovery would be worth at least $300 trillion and provide an unlimited supply of energy to the world. Other laboratories around the world tried to duplicate this experiment. All failed. Fleischmann claimed other scientists were not using the correct materials or procedures and that he was not going to reveal the exact nature of his experiment. The majority of scientists do not believe cold fusion is possible—at least at this time and at the current state of technology. Nuclear fusion requires an extremely high temperature and pressure such as is achieved in the sun and thermonuclear H-bombs to "fuse" the light hydrogen nuclei to form heavier helium nuclei, producing a great deal of energy in the process. The debate continues, but only a few scientists believe Fleischmann's cold nuclear fusion can take place as he described the process. Pons and Fleischmann parted ways in 1995. Reportedly, Pons is no longer in the research field, and Fleischmann now works in the private sector.

See also Bethe; Teller; Ulam

FLEMING'S BACTERICIDE HYPOTHESIS: Biology: *Sir Alexander Fleming* (1881–1955), England. Sir Alexander Fleming, Baron Florey, and Ernst Boris Chain shared the 1945 Nobel Prize in Physiology or Medicine.

> *If the* Penicillium notatum *mold growing in a laboratory dish can destroy staphylococcus bacteria, then it can be tested to destroy other selected harmful bacteria.*

Sir Alexander Fleming, a bacteriologist in the Royal Army Medical Corps, was familiar with the use of chemicals in the treatment of wounds. He devised *lysozyme*, an enzyme found in human tears and saliva, which proved to be a more effective bactericide than the chemicals available to him at the time. Even so, lysozyme was limited in its effectiveness. A few years later while examining a dish containing a culture of staphylococcus bacteria, he noticed several clear areas where the bacteria did not grow due to the presence of a mold identified as *Penicillium notatum*, which seemed to kill the harmful bacteria. Based on his experience with bacteria, Fleming recognized the potential for a new antibiotic but, at first, neglected to follow up on this discovery. It had been known for many years that some molds kill "germs," but no one had acted on it until Fleming finally recognized the importance of this phenomenon. Fleming's mold was isolated, developed, and tested for effectiveness by other scientists in Great Britain. By 1943 Fleming's discovery led to the production of limited amounts of penicillin, which saved the lives of many wounded Allied servicemen and women during World War II. Since then, a large number of similar "molds" have been identified and produced to provide a wider selection of antibiotics useful in the treatment of a variety of diseases.

See also Florey

FLEMING'S RULES FOR DETERMINING DIRECTION OF VECTORS: Physics: *John Ambrose Fleming* (1849–1945), England.

Fleming's right-hand and left-hand rules: *The right-hand rule (also known as the generator rule) is related to the Cartesian coordinate system for the three-dimension x, y, and z*

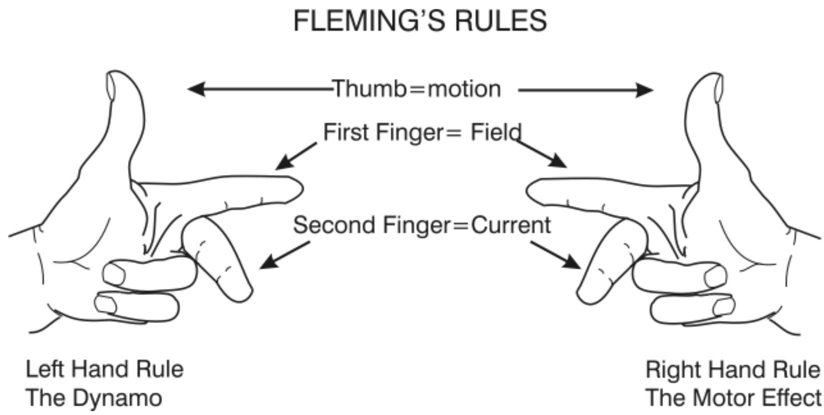


Figure F4. The right-hand and left-hand rules are designed as an easy way to remember the direction of the current, the magnetic field generated, and the motion of either the electric motor or generator.

axes for electric dynamos; while the left-hand rule (also known as the motor rule) is used to determine similar x, y, and z dimensions for electrical motors (*see* Figure F4).

Essentially, Fleming's right-hand and left-hand rules were conceived as easy-to-remember representations of electromagnetism and a means for determining 1) the direction of the flow of the electric current, 2) the direction of the field around the conductor carrying the electric current, and 3) the direction of the force involved in the operation of electric motors and electric generators. As shown in Figure F4, if the forefinger, second finger, and thumb of the *right hand* are extended at right angles to each other, the forefinger indicates the direction of the field, the second finger the direction of the current, and the thumb the direction of the force and in the dynamo (electric generator). Conversely, the *left hand* illustrates the same positions of the fingers and represents the same characteristics, except for electric motors. In other words, a person's hands are convenient tools to help remember the vectors associated with the directions of flow of current, the current's field, and force for the motor and dynamo. The diagrams help visualize the directions of magnetic forces and fields produced by conductors carrying electric currents.

Although the motor and dynamo are similar electrical devices, they perform opposite functions. The dynamo uses mechanical force to turn an armature to cut through the magnetic fields to produce a flow of an electric current, whereas a motor uses electric current to turn an armature in the magnetic field to produce a mechanical force.

In early life, John Ambrose Fleming showed evidence of being a child prodigy when, at the age of thirteen, he gave his first lecture on electricity and magnetism. He was educated primarily at the University College in London, the premier college of London University where he received his BS degree in 1870. He taught school for a few years to support his continuing education and later studied under the famous British physicist James Clerk Maxwell at Cambridge University. In 1885 he created and headed a new department of electrical engineering at University College in London. Fleming was a popular lecturer and consultant, who also conducted research for wireless signal transmissions across the Atlantic Ocean. He designed the transmitter that made the first successful wireless transatlantic transmission in 1901.

Fleming's theory for rectifying alternating current (AC) to direct (DC) current: *By adapting and using the Edison effect (see Edison) to construct a two-electrode vacuum-tube rectifier to act as an oscillation valve (also called a thermionic valve, vacuum diode, kenotron, and thermionic tube), it is possible to convert an alternating current into a direct current.*

The Fleming valves were the beginning of the electronic age and were used in early radio and radar instruments. The American inventor Lee De Forest added a third electrode to the Edison/Fleming diode that acted as a "grid" that could be used to control the flow of electrons across the gap from the hot negative electrode to the cool positive electrode. This formed what was known as a triode that could be used to amplify electronic signals as well as modulate sound signals that led to long-distance wireless communication systems of today, including radio, television, radar, computers and, the Internet.

FLEROV'S THEORY OF SPONTANEOUS FISSION: Physics: *Georgii Nikolaevich Flerov* (1913–1990), Russia.

> *Uranium nuclei will fission spontaneously, and the process requires no bombardment of the nuclei by neutrons to accomplish the splitting of the nuclei.*

In 1941 Flerov observed spontaneous fission where the nuclei of uranium nuclei break into nuclei of smaller, lighter elements. This fission occurs naturally without the bombardment of the uranium nuclei by additional neutrons. Flerov was familiar with scientific journals that indicated that scientists from other countries were working with this natural fission, as well as attempting to cause artificial fission by bombarding nuclei of heavy elements with slow neutrons to cause them not only to fission, but also to cause a chain reaction. He urged the Soviet government to initiate a research program to investigate this phenomenon.

Georgii (or Georgy) N. Flerov was the Soviet Union's leading nuclear physicist and soon became the leader of a team of scientists at the Joint Institute for Nuclear Research (JINR) at Dubna in Russia. In 1942 he wrote to Joseph Stalin, the infamous Communist leader of the Soviet Union, about the progress being made in developing a nuclear bomb in the United States and Germany. His efforts eventually led to the Union of Soviet Socialist Republics' (USSR) production of their own atomic bomb.

Flerov's team at Dubna claimed in 1967 to have isolated the isotopes of the elements with the mass number (atomic weights) of 260 and 261 by bombarding the isotope americium-243 with the isotope neon-22 ions. They had created the element with an atomic number of 105 (number of protons in the nucleus), for which they suggested the name *nielsbohrium* in honor of the Danish physicists Niels Bohr. The reaction follows: ${}_{95}\text{Am-243} + {}_{10}\text{Ne-22} \rightarrow {}_{105}$ nielsbohrium-260 and -261.

The American group under the direction of Albert Ghiorso at the Lawrence Berkeley National Laboratory in Berkeley, California, could not confirm the Dubna results. However, by using different techniques they synthesized an isotope of element 105. They bombarded californium-249 nuclei with nitrogen-15 ions and created an isotope with an atomic weight of 260 and a half-life of 1.6 seconds, which was long enough to positively identify it as a new element with atomic number 105. It was then named *hahnium* in honor of the physicist Otto Hahn. Over the next few years two other disputes about the name for element 105 arose. In 1994 a committee of the International Union of Pure and Applied Chemistry (IUPAC) named 105 *joliotium* (Jl-105) after the French physicist Frederic Joliot-Curie. Still later in 1997 an international agreement between Russia and the United States led to the acceptance of the name *dubnium* (Db or Unp) for the new artificially produced element with 105 protons in its nuclei. This name was decided upon because of the original work done with this element by the Dubna group in Russia. Since then, the Russian and American nuclear laboratories (as well as one in Germany) went on to produce isotopes of additional heavy elements up to and beyond element 118.

See also Curies; Hahn; Seaborg

FLOREY'S THEORY OF MUCUS SECRETIONS: Biology: *Howard Walter Florey (Baron Florey of Adelaide)* (1898–1968), Australia. Baron Florey shared the 1945 Nobel Prize in physiology or medicine with Sir Alexander Fleming and Ernst Chain.

Mucous secretions that contain lysozyme can destroy the cell walls of bacteria.

Following up on Sir Alexander Fleming's work with the enzyme lysozyme, Baron Florey determined how this enzyme found in tears and saliva destroyed the cell walls of bacteria. This research led to Ernst Chain's (1906–1979), the German-born British biochemist, and Baron Florey's idea for developing *penicillium*, an antibiotic discovered earlier by Fleming. Although Fleming discovered *penicillium* and recognized that it killed staphylococcus bacteria, he did not pursue its commercial development. Chain's and Florey's efforts brought to fruition the success of this and other similar effective antibiotics used to treat numerous types of bacterial infections.

Baron Florey continued his work on other antibiotics as well as experimental procedures involving pathology and the lymphatic and vascular systems. Although he lived most of his life in England, in spirit he remained an Australian.

See also Fleming (Alexander)

FLORY'S THEORY OF NONLINEAR POLYMERS: Chemistry: *Paul John Flory* (1910–1985), United States.

Polymer molecules have a definite size and structure consisting of multiple macromolecules with different chain lengths that are branching as well as linear.

Macromolecules are an aggregate of two or more molecules that are not combined by regular chemical bonds, but rather by intermolecular forces acting between the molecules themselves (*see* the Van der Waals force). A distinction between regular smaller molecules and macromolecules is that smaller molecules are easily dissolved in a liquid whereas macromolecules need some type of assistance to dissolve. Rarely do macromolecules occur individually, but they are more likely to assemble into *macromolecular complexes*. However, proteins are considered *subunits* of such macromolecular complexes. The IUPAC (the International Union of Pure and Applied Chemists) prefers the term "macromolecules" for grouping of individual molecules. The term "polymer" is something that consists of many macromolecules with either a linear or multiple branching structures. There are many polymers whose molecules consist of many thousands of atoms formed into long linear chains. But not all polymers are linear. Most polymers are branched chains where both ends of the branched chains are attached to a backbone chain of separate molecules, and it is possible for backbone chains to become attached to each other to form very large polymer molecules. Some of these are cross-linked polymers that are groups of molecules large enough to pick up in your hand, such as synthetic rubber. Liquid crystals and DNA are examples of polymer-type macromolecules. For example, chromosomes of DNA can be tens of millions of base pairs in length.

Paul John Flory used statistical methods to determine the length and branching of chains of molecules from which he developed his theory of cross-linking between molecular chains to form linear chains as well as branching liquid macromolecules that became known as polymers. Most plastics, artificial rubber, and other materials are composed of polymers. For example, bowling balls are considered a single polymer macromolecule, whereas computer cases, telephones, tires, and many other everyday items, including synthetic motor oil, artificial blood, and new types of liquid crystals used in screens for some electronic instruments, are all forms of branching polymer macromolecules.

FOUCAULT'S THEORIES OF LIGHT AND EARTH'S ROTATION: Physics: *Jean Bernard Leon Foucault* (1819–1868), France.

Foucault's wave theory of light: *If light is a wave, it will travel faster in air than in water; if light is a particle, it will travel slower in air than in water.*

To test his theory, Jean Foucault required a more accurate means of determining the speed of light than resulted from Armand Fizeau's rotating "toothed disk" device experiment conducted some years earlier. He devised a system using a rotating mirror, which provided a measurement very close to that later achieved by Albert Michelson. Foucault's mirrors were located on hills 22 miles apart. This greater distance made his measurements more accurate. The turning mirror reflected the light back at a slightly different angle to another mirror. This slight angle of reflection could be measured and compared with the rate of rotation of the mirror to give the approximate speed of light. The formula is $v = c \div n$, where v is the speed of light through a particular medium, c is the constant for the speed of light in a vacuum, and n is the index of refraction of the medium through which the light is being measured. He repeated a similar procedure with light projected through water and found that the reflection angle, and thus the speed of light through water, is less than when it travels through air (*see* Figure F5). For instance, the speed of light is approximately 186,000 miles per second, or exactly 299,792,458 kilometers per second in a vacuum. To find the velocity of light through water, divide 186,000 by the index of refraction of water, that is 1.33, which results in the speed of light through water at about 140,000 miles per second. This was the proof he needed to arrive at his theory for the wave nature of light, which upset many scientists of his day because of their belief in Newton's theory that light was composed of minute particles (photons). Later scientists accepted the duality of light as having both a wave and particle nature (*see also* Fizeau; Huygens; Michelson).

Foucault's theory for the rotation of Earth: *Because a pendulum swings in an unchanging plane, its apparent progressive movement out of the plane must be caused by the rotation of the earth beneath the pendulum.*

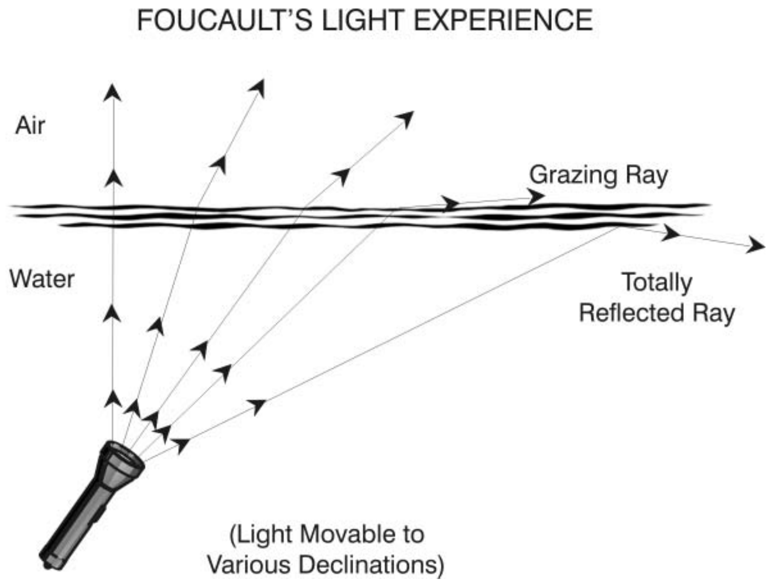


Figure F5. Light rays are "refracted" as they pass through substances of different densities at an angle to the normal (the line perpendicular to the surface). They will change directions when going through the boundary between the two different substances according to their angle of entrance to the boundary. The index of refraction is the ratio of light's speed (in a vacuum) to its speed in a given material.

Jean Foucault was familiar with the work of Galileo, who applied the periodic motion phenomenon of a pendulum to measure time. Galileo used his heart pulse to time the frequency of the pendulum "bob," which he determined is inversely proportional to the length of the string suspending the bob. This means that the shorter the string, the greater the frequency of the swinging bob, and conversely, the longer the string, the lower the frequency. Needing an accurate timing device to measure the speed of light, Foucault considered a pendulum. He knew the pendulum executed a form approximating simple harmonic motion where the force that "drove" it was outside the system (i.e., gravity). He noticed the pendulum appeared to stay in the same plane (compass direction) even when the platform holding the pendulum apparatus was rotated. Recognizing the significance, he determined that because the pendulum always moves in the same plane, it must be Earth beneath the swinging pendulum that turns. He performed a demonstration during which he suspended an iron ball weighing 28 kilograms from a 67-meter wire attached to the top of the inside of Le Pantheon in Paris. Sand was spread out on the floor under the pendulum and a needle was attached to the bottom of the ball weight of the pendulum. When set in motion, the needle slowly inscribed a pattern in the sand, proving that Earth was moving under the pendulum.

This was the first Earth-based demonstration that proved that Earth actually rotates on its axis, but not at the same rate at all latitudes. For instance, at the equator, an east-west swinging pendulum will show no rotation motion of earth because Earth and pendulum are moving in the same east-west direction while Earth rotates once every

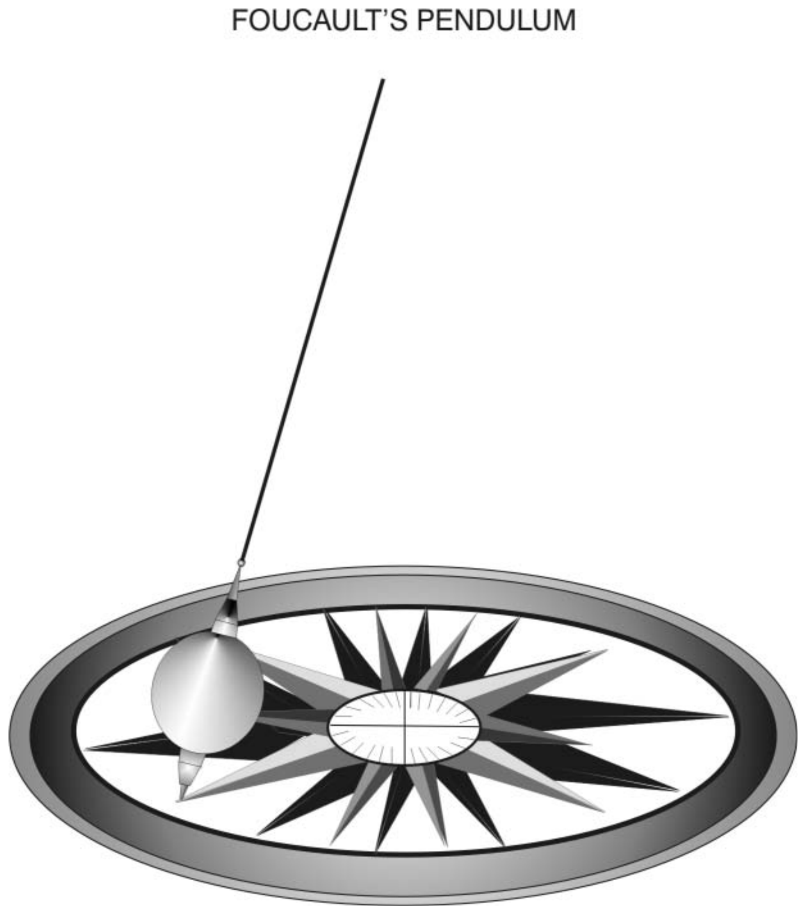


Figure F6. Foucault's Pendulum.

twenty-four hours. Also, at the North Pole, Earth makes a complete rotation every twenty-four hours under a pendulum swinging in the same plane. Thus, an east-west swinging pendulum will stay in the same plane while the Earth turns under it. The effect differs with the latitude from the equator to the poles. The formula for determining the period of rotation at latitudes other than at the Earth's poles or at the equator is $P = 23^h\ 56^m \div \sin$ (latitude). The pendulum used to measure Earth's rotation is called *Foucault's pendulum*.

Pendulums are also used to measure acceleration due to gravity and velocities (the *ballistic pendulum*), as well as for accurate clocks. Seventy years after Galileo's study of the pendulum, Christiaan Huygens incorporated it into an accurate timekeeping instrument. Called the grandfather's clock, it used a weight system to continue the "force" to overcome friction and thus maintain the pendulum's constant swing. There is also a *compound pendulum* where a rigid body swings around a central point. One model, designed by the British physicist Henry Kater (1777–1835), measured acceleration due to "free fall," which can then be used to calculate the force of gravity.

See also Galileo; Fizeau; Hooke; Huygens

FOURIER'S THEORIES OF HEAT CONDUCTION AND HARMONIC WAVE MOTION: Physics: *Jean-Baptiste-Joseph, Baron Fourier* (1768–1830), France.

Fourier's theorem of heat conduction: *The rate at which heat is conducted through a body, as related to that body's cross section area, is proportional to the negative of the temperature gradient existing in that body.*

Baron Fourier worked out the mathematical expression for conduction of heat through different types of solid materials. The theory explains why excellent heat conductors are also good electrical conductors. Conduction relates to the motion of free electrons in solid matter when a temperature difference exists from one end of the matter to the other. The proportionality constant of his equation is referred to as the *thermal conductivity* of the solid. For instance, glass, wood, paper, and asbestos all have thermal conductivities of a much lower value than metals. They are referred to as *insulators* of heat and electricity. Conversely, most metals have a high value of thermal conductivity and are excellent conductors of heat and electricity. Conduction is one of three forms of heat transfer described in physics. The other two are convection and radiation. Modern technology and industry use the mathematics of heat transfer and the temperature differential for various materials. Fourier's theory was the beginning of dimensional analysis, which requires any expression of unit quantities to be balanced in equations just as are numbers. One of his main contributions was the establishment of linear partial differential equations that are used as a powerful tool in mathematics and to determine boundary values in physics problems such as heat conduction in different substances. Today, computers calculate the equations for these properties of different substances.

Fourier's harmonic analysis: *Any periodic motion (wave pattern) can be separated mathematically into the individual sine waves of which the pattern is composed.*

Robert Hooke's law of elasticity states that the change in size of an elastic material is directly proportional to the stress (force applied per unit area) applied to the material. Hooke applied this concept to thermal expansion and wave motions of metal spiral springs. Baron Fourier believed that complicated wave motions were not all that complex and could be solved mathematically. His work, referred to as *wave analysis*, is applied to music. Pythagoras was the first to determine that certain musical notes blend together to produce pleasant sounds. He also ascertained these notes represent a ratio of small whole numbers. Pythagoras used strings of different lengths to define "nice" sounds (e.g., 1:2; 2:3; and 3:4 string-to-length ratios). Musical sounds consist of a number of separate sine waves that, when combined, display some order of interrelationship. These ordered sets of sine waves, which may or may not reinforce each other, produce musical notes. If the sine waves are randomly selected and combined or interfere with each other it results in dissonance we call *noise*. Fourier's wave analysis techniques established a firm physical and mathematical basis for modern music and the development of musical instruments.

See also Hooke; Pythagoras

FOWLER'S THEORY OF STELLAR NUCLEOSYNTHESIS: Physics: *William (Willy) Alfred Fowler* (1911–1995), United States. Willliam Fowler shared the 1983 Nobel Prize in Physics with Subrahmanyan Chandrasekhar.

Thermonuclear fusion reactions in stars produce enough kinetic energy to overcome the electrostatic repulsion of hydrogen nuclei to form helium nuclei. Additional fusion *reactions produce even more kinetic energy to overcome the repulsion between other nuclei, thus producing the heavier elements.*

A number of scientists, including Georges Lemaître, George Gamow, and Sir Fred Hoyle have proposed their versions of the big bang theory. William Fowler expanded on this theory, which propounds that the explosion of a tiny "seed," "point source," or "singularity" of energy, which created tremendous radiation and energy, forming in less than a few seconds mostly hydrogen atoms, resulted in the formation of the entire universe soon after this singular beginning. None of the scientists have claimed to know what caused the "explosion" or the origin of the "seed," or the singularity of energy/matter. The big bang theory further states the colossal amount of energy provided the force for two hydrogen nuclei ($^{+}H + {}^{+}H$) to combine to form a helium nucleus (^{++}He) creating **thermonuclear** energy in the stars. This reaction occurred at temperatures of about 10 to 20 million kelvin (K). The reaction did not produce enough energy to overcome the mutual electrostatic repulsion of the double-charged helium nuclei (alpha particles); thus this temperature was insufficient to form nuclei of the heavier elements. Following the lead of several other physicists, Fowler developed the theory that this temperature in the core of the sun became much greater, up to 100 to 200 million K, and produced enough kinetic energy to overcome the mutual repulsion of the positive alpha particles, which then combined to form the nuclei of heavier elements. First, a fusion reaction occurred, which combined three alpha nuclei (3 ^{++}He) to form a carbon nucleus with 6 positive protons ($^{++++++}C$). This thermonuclear reaction increased the temperature to over 500 million K, which provided the energy to fuse an alpha nucleus (^{++}He) with a carbon nucleus ($^{++++++}C$) to form an oxygen nucleus ($^{++++++++}O$) with eight protons. These stellar thermal nucleosynthesis (fusion) processes continued, reaching over one to three or four billion degrees, thus forming the other heavier elements that make up Earth and the universe. Fowler's work aided the understanding of the composition of stars, our solar system, and the nature of the universe, that is, its age and future. He and Fred Hoyle cooperated and published an important paper "Nucleosynthesis in Massive Stars and Supernovae" in 1965 that explained how heavier elements were formed as the temperature increased inside stars.

See also Gamow; Hoyle; Lemaître

FOX'S THEORY OF PROTEINOID MICROSPHERES: Biochemistry: *Sidney Walter Fox* (1912–1998), United States.

Using heat, thermal proteins will self-organize into protocell-like microspheres.

Since the beginning of time humans have wondered about their biological origins, life, death, and the reason we are on Earth. The Greeks referred to this particular curiosity as *abiogenesis*, a Greek word meaning "a genesis of nonbiological origins." Later in history it was known as the spontaneous generation of life. In the Middle Ages it was thought that rats and mice were "generated" from grain or old hay that was stored over long periods of time, and that maggots/flies came from spoiled meat and food. Even Aristotle believed that small insects grew out of the dew from the flowers and leafs of plants. These ancient beliefs were not corrected until 1668 when Francesco Redi conducted an experiment that proved that maggots did not come from spoiled meats. He placed a gauze barrier over the mouth of jars of meat that prevented flies from touching the meat (*see* Redi for details of this experiment). Numerous other famous scientists and researchers devised other theories for the generation of life. In the 1930s the Soviet biologist Alesksandr Ivanovich Oparin and others produced molecules that could "grow" and fuse together and form into daughter cells. John Burdon Sanderson Haldane, the British geneticist and evolutionary biologist, believed that life formed in a "soup" containing organic substances. Many other scientists theorized about the origin of living things, including Leeuwenhoek, Spallanzani, Darwin, and Pasteur. This concept became known as "biopoiesis," which is the formation of biological substances, or as "autopoiesis" that is defined by American biologist Lynn Margulis as the self-organizing of living systems that have properties that maintain their own boundaries. The concepts involve the "spontaneous" formation of simple inorganic chemicals into more complex organic molecules on Earth. The concept of "panspermia" is the belief that life came to Earth from some other planet or asteroid in the universe. The astronomers Sir Fred Hoyle and the Sri Lankan astrobiologist Chandra Wickramasinghe (1939–) believed in panspermia. In 1953 Stanley L. Miller and Harold C. Urey while at the University of Chicago placed a "primeval soup" composed of water vapor, methane, ammonia, and hydrogen, but no oxygen, in a closed container. They then shot electrical sparks though this "soup" to represent lightning which they hypothesized might provide the energy required to form organic molecules and thus might represent the environment on the early Earth. They did demonstrate that complex molecules can be formed from simple amino acids, but alas, they did not create life.

Sidney Fox was one of several biochemists to have conducted experiments on the origins of life. In 1984, 1985, and 1990, Fox was invited to discuss his work related to the creation of life before Pope John II and other papal scientists in Rome in a forum sponsored by the Italian Academia dei Lincei, IBM, and the National Foundation for Cancer Research. It appeared that the Pope wanted to be as well informed as possible before issuing the Roman Catholic Church's famous statement in support of the scientific theory of organic evolution. Fox assumed there were three reasons for the Pope's interest in his research on the origins of life and subsequent evolution of plant and animal species. Pope John II's interests appear to be related to where he and everyone else came from, how future evolutionary research might be related to Genesis; and last, the Pope did not want to repeat the mistakes that the early Church made regarding Giordano Bruno (burning at the stake), Copernicus (his book on the heliocentric universe remained on the Index for one hundred and fifty years), and Galileo (condemned by the Inquisition), as well as other less-famous philosophers and scientists who were either excommunicated or suffered similar fates. Fox's lectures were well received by the Vatican.

Sidney Fox's 1958 experiment did produce a type of polymer (long chain of molecules) of amino acids that he called "proteinoids" by the application of heat. In turn these proteinoids tended to form "microspheres" that resembled bacteria-like "protocells" which were about a micrometer in size. These tiny protocells developed a membrane on their surface that seemed to produce "buds" that, under certain conditions, divided. Since then others have attempted to "create" life by developing an understanding of the complexity of inorganic substances as they react and interact to form basic organic type molecules. If the question is whether simple chemicals and substances can form the molecules of life, the answer seems to be yes. However, to date, the "spark" that is life has not been scientifically identified and found.

See also Hoyle; Miller; Urey

FRACASTORO'S THEORY OF DISEASE: Biology and Medicine: *Girolamo Fracastoro* (1478–1553), Italy.

Diseases are transmitted by ''seedlike'' entities that are transferred from person to person.

Girolamo Fracastoro recognized that invisible "seed-like" particles transmitted infection. In 1546 Fracastoro wrote *On Contagion and Contagious Diseases* in which he anticipated the germ theory. In this book he mentioned three types of infection: 1) by direct contact of an uninfected person with a person infected by the disease; 2) by indirect contact with the infected person by some path, such as clothing, infected air, food, or other medium that could carry the infection; and 3) contagion from a distance, where there is no evident contact between the infected person and a noninfected person, such as a fever. In all three cases, the disease is transmitted by "seeds of contagion" that are capable of reproducing themselves and thus spreading diseases. He also stated that each disease has it own nature of contagion, that is, types of "seeds," that have their own rate of multiplying as tiny bodies that carry the disease. Unfortunately, his observations and theory made little impact on the actual status of medicine of his day, although it was influential for several centuries until the early nineteenth century when Agostino Bassi (1773–1856), the Italian biologist and bacteriologist, proposed his germ theory in 1825.

Before his contagion theory Fracastoro was known for his book *Syphilis, or the French Disease* published in 1530. This book introduced the term "syphilis" to Europeans. The Italians called it the French disease. The French called it the Italian disease. And all Europeans believed syphilis was imported from the New World by explorers returning to their homes in Europe. It was more likely in the 1500s that infected sailors and settlers from Europe infected Native Americans than the other way around.

See also Leeuwenhoek; Pasteur

FRANCK'S THEORY OF DISCRETE ABSORPTION OF ELECTRONS: Physics: *James Franck* (1882–1964), United States. James Franck and Gustav Hertz shared the 1925 Nobel Prize for Physics.

Only electrons at specific velocities can be absorbed by a medium (mercury) in precise (quanta) amounts.

In 1914 James Franck and the German experimental physicist Gustav Hertz (1887–1975) collaborated to demonstrate experimentally that energy is transferred in selected quantized amounts as it reacts with atoms and other particles. They used electrons at different velocities to bombard mercury atoms and discovered that electrons could be absorbed by the mercury atoms only and exactly at 4.9 electron volts of energy. If the electrons had less energy, they were lost on collision with the nuclei of the mercury atoms. If the energy was greater than 4.9 eV, they were not absorbed. It was only at the discrete 4.9 eV of energy that electrons were permitted to enter the orbits of the mercury atoms. This was the first experimental evidence for the *quantum* (Latin for "how much") theory of energy and was later confirmed for the "quantum leap" of electrons for other atoms. A simplified explanation of the quantum leap states that it is a tiny, discrete amount of energy emitted by an electron when it jumps from an inner orbit to an outer orbit (energy level). The closer an electron's orbit is to the nucleus, the greater is its energy. Therefore, as it jumps from an orbit of greater energy to an orbit of lesser energy (further from the nucleus), it must give up a "quantized" bit of energy. The energy emitted is a photon (light particle). Conversely, when an atom absorbs a specific level of energy, an electron in an outer orbit can take a quantum jump down to an inner orbit (*see* Figure D6 under Dehmelt). Franck's and Hertz's experimental proof of the quantum theory was an important step in understanding the physics of matter and energy.

See also Dehmelt; Heisenberg; Hertz; Planck

FRANKLAND'S THEORY OF VALENCE: Chemistry: *Sir Edward Frankland* (1825–1899), England.

> *The capacity of the atoms of elements to combine with the atoms of other elements to form molecular compounds is determined by the number of chemical bonds on the given atoms.*

Sir Edward Frankland is considered the father of the concept of *valence* (Latin for "power") that is the number of chemical bonds (connections), atoms, or groups of atoms that can be exchanged or shared with other atoms. In his work with organic compounds, Frankland discovered that atoms of different elements would chemically bond within fixed ratios with other groups of atoms. From this observation in 1852, he developed an explanation for the maximum valence for each element. The theory of valence explained the relationships of atomic weights with the ratios of atoms combining with each other (*see* Figure S3 under Sidgwick). Although valence is the "combining power" of atoms to join with each other to form molecules, the electrovalence of an ion (atoms that lost or gained electrons) is the numerical value of the electrical charge on the ion. The concepts of valence and electrovalence are important for the understanding and advancement of chemistry. Later in 1867 Frankland and his colleague, the British chemist B.F. Duppa (dates unknown), identified and determined that the –COOH (Oxatyl) group is a found in all organic acids. This simplified the determination for the structure of many organic compounds.

See also Abegg; Arrhenius; Berzelius; Bohr; Dalton; Langmuir; Lewis; Sidgwick

FRANKLIN'S CONCEPT OF DNA STRUCTURE: Physics: *Rosalind Franklin* (1920–1958), England.

> *The complex organic DNA molecule is a helix structure with phosphate chemical groups situated on the outer boundaries of the helix spirals.*

Rosalind Franklin, an expert crystallographer, made X-ray photographs of a form of DNA that clearly indicated the helix nature of its molecular structure.

As the story goes, in 1952 James Watson viewed her X-ray photographs and recognized the importance of the obvious helix structure of the DNA substance to the DNA research he and Francis Crick were conducting. Crick obtained copies of Franklin's X-ray photographs from her boss Maurice Wilkins (1916–2004) (some say without her

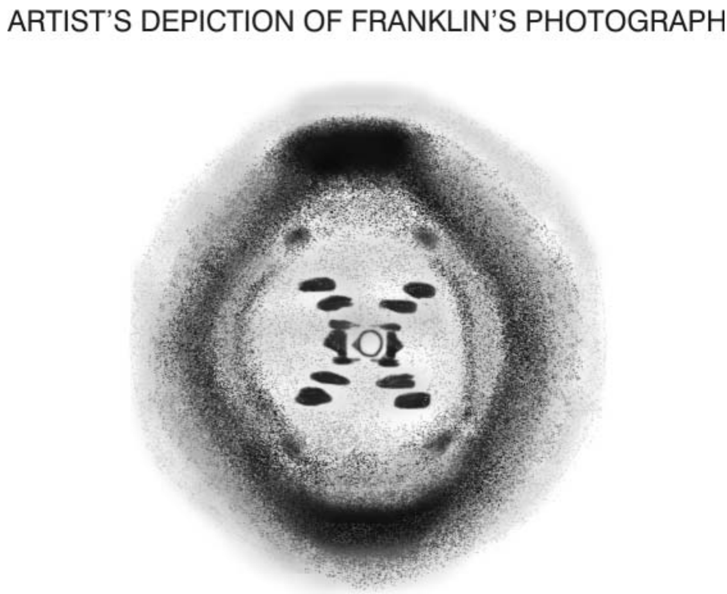


Figure F7. Rosalind Franklin's X-ray crystal photograph of the helix structure of the DNA molecule.

permission). These photographs clearly provided the information required for Watson and Crick to develop an acceptable helix structure of the double helix of DNA (*see* Figure C5 under Crick). Rosalind Franklin later wrote a paper in which she mentioned the structure for the DNA molecule that consisted of a double-chain helix. Although she did not recognize the complete structure nor did she recognize the inclusion of base pairs of nucleotides, she did indicate that the phosphate groups on the outside of the strands were responsible for holding the units together. In the publication that reported the structure of the DNA molecule, Franklin was not given credit for her important work or her X-ray photographs. The 1962 Nobel Prize for Physiology or Medicine was awarded to Watson, Crick, and Wilkins, but because Rosalind Franklin had died of cancer in 1958 she was ineligible for the award.

See also Crick; Watson

FRANKLIN'S THEORIES OF ELECTRICITY: Physics: *Benjamin Franklin* (1706–1790), United States.

Franklin's single fluid theory of electricity: *Electricity is a single fluid with both attracting and repelling forces*.

Benjamin Franklin knew of other scientific experiments that demonstrated that when substances (then called "electrics," and now are known as insulators) such as amber and glass, were rubbed with wool or silk, static electricity was produced. Conversely, when "nonelectrics," (now known as conductors) such as metals, were rubbed, no static electricity was produced. Based on this evidence, scientists concluded that because rubbing different substances could produce a repelling or attracting force, electricity must be composed of two different types of fluid. The French chemist Charles

Du Fay (1698–1739) proposed the concept of two kinds of electricity: positive and negative. He called the positive electricity *vitreous* and the negative *resinous*, which seemed to confirm the "two fluid" nature of electricity. In 1747, after experimenting with a **Leyden jar**, Benjamin Franklin advanced a single fluid concept of electricity, but he still considered it a "flowing" substance.

> Benjamin Franklin might be considered an eighteenth-century Renaissance man because of his eclectic interests and endeavors. Not only was he interested in many areas of science, he was also an accomplished diplomat, politician, publisher, and wit. Two of his famous publications, are the *Pennsylvania Gazette* from 1729 to 1733, which was followed by the more successful *Poor Richard's Almanac.* He also published works on heat, light, and oceanography. He made measurements of the temperature of the water in the Gulf Stream and determined how this moving body of water affected the northern part of the United States and Western Europe. His data was used to develop accurate maps of the Gulf Stream. Among his many inventions were a new type of home heating stove (now referred to as the "Franklin stove,") bifocal eyeglasses, and the rocking chair. He lived a long, productive life. He believed that life should be lived to its fullest potential.

Franklin's concept of electric charges: *Because electricity is a single fluid substance, two types of forces must be present to cause attraction and repulsion.*

Benjamin Franklin, as well as Du Fay, is credited with the terms "positive" and "negative" to explain the attraction and repulsion characteristics of "fluid" electricity. Franklin's single fluid electricity was on the right track, even though he interpreted the terms incorrectly. He reasoned that "positive" would be the direction of the current flow, when in actuality the negative electrons determine the direction of the electric current toward the positive pole, which lacks electrons, and thus has a potential of gaining electrons. This has caused much confusion ever since.

Franklin's concept of lightning: *Lightning is a form of electricity that is more strongly attracted to points, particularly metal points at high altitudes.*

For many years, scientists' related lightning to static electricity because both produced a jagged spark of light and could cause shock. But there was no proof they were the same phenomenon. Benjamin Franklin's experiments with the Leyden jar illustrated that electricity was more strongly attracted to point sources than to flat surfaces. From this concept, he believed it possible to demonstrate that lightning was an electrical discharge by attracting it to a metal tip on the end of kite. The result was his famous kite experiment during a thunderstorm in the year 1752, when lightning was attracted to the kite and was conducted to a silk ribbon attached to a metal key. When he brought his knuckle close to the key, a spark jumped to his hand, producing a mild shock. This was a very dangerous experiment, and several scientists were electrocuted when trying to replicate Franklin's demonstration that proved lightning is electricity. However, this experiment forged Franklin's development of the lightning rod, which has prevented lightning damage to many homes and commercial buildings.

FRAUNHOFER'S THEORY OF WHITE LIGHT: Physics: *Josef von Fraunhofer* (1787–1826), Germany.

> *White light projected through a prism produces a continuous color spectrum that is crossed by dark lines.*

Josef Fraunhofer was an expert lens maker familiar with Isaac Newton's studies that proved white light is composed of colored lights when it is projected through a prism.

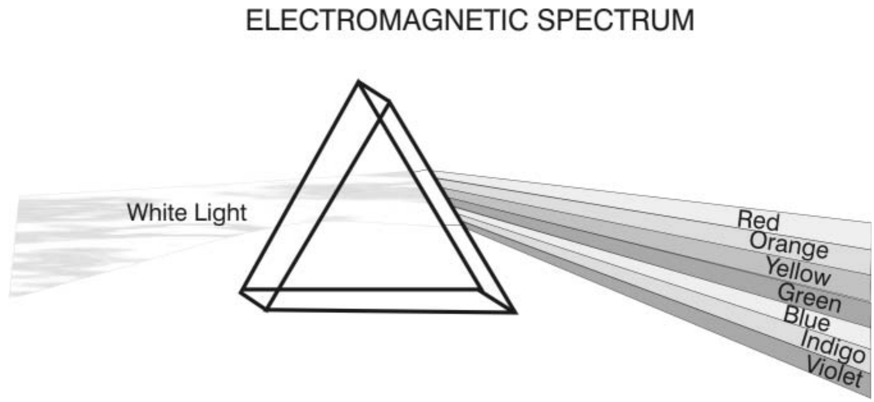


Figure F8. An artist's rendition of the electromagnetic spectrum produced by a beam of white light passing through a prism. The white light is composed of separated electromagnetic waves ranging from long infrared to short ultraviolet rays.

Fraunhofer was also familiar with the English chemist and physicist William Hyde Wollaston's (1766–1828) observation that dark lines within a spectrum were produced from a white light source. As Fraunhofer permitted light from a very narrow slit to pass through one of his excellent prisms, he observed a series of narrow bands of light of varying wavelengths. Some images of specific wavelengths (colors) were missing and produced the dark lines reported by Wollaston. Fraunhofer did not know what caused them nor did he realize their significance, but they were then, and still are, referred to as *Fraunhofer lines*. Fraunhofer went on to identify over seven hundred of these dark lines. Later, Robert Bunsen (inventor of the Bunsen burner) and Gustav Kirchhoff, using a spectroscope, determined that the dark lines were the absorption of specific wavelengths of light by a vapor between the source and the prism. This concept of radiation absorption was used to identify numerous new chemical elements by spectroscopy (spectro analysis). The same concept can be used to study the nature of light from the sun and stars to determine their chemical composition.

See also Bunsen; Kirchhoff; Newton

FRESNEL'S THEORY FOR MULTIPLE PRISMS: Physics: *Augustin Jean Fresnel* (1788–1827), France.

> *A single beam of light produces multiple interferences when split into multiple beams of multiple prisms.*

Augustin Fresnel considered light to be similar in nature to sound waves. Based on this concept, he worked out the mathematics for light as transverse waves that explained reflection, refraction, and diffraction, which are related to the longitudinal waves for sound. His work with the interference of the beam of light by a prism caused him to consider what would happen if two prisms were used to split the beam of light into two parts. Fresnel conceived of a series of prisms formed as concentric circles on a circular glass lens. This resulted in the Fresnel lens, which, from the front, looks like concentric circles similar to a bull's-eye on a target, but from a cross section, these circles appear as a series of "sawtooth" tiny circular prisms.

The Fresnel lens, first developed to concentrate the light from lighthouses, is now used in a multitude of devices, from overhead projectors, to large-format cameras, to other devices with screens too large to make use of a heavy glass convex lens to concentrate light.

August Fresnel also used transverse waves to explain the phenomenon of polarization of light. The electric field **vector** oscillates in directions perpendicular to the direction of light. Light is polarized when the electric field oscillates just up and down or right and left. If the electric vector oscillates in all directions, the light is said to be unpolarized. (Today, sunglasses use lenses that transmit the one-directional polarized light waves, while blocking out most of the light with the opposite polarization.) This seemed to settle the controversy of the nature of light as a wave, at least until the light particle (photon) theory was developed.

See also Einstein; Fizeau

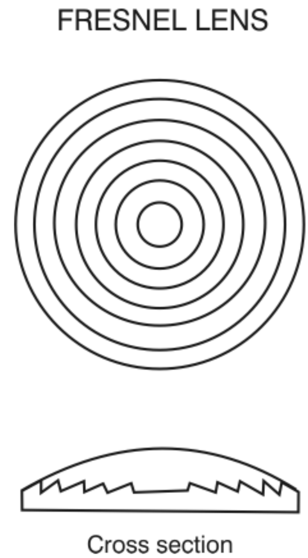


Figure F9. From the front, the Fresnel lens looks similar to a bull's eye, but from the side it appears as a series of "saw-tooth" circular prisms. It is used to concentrate light.

FRIEDMAN'S THEORY OF THE QUARK STRUCTURE OF NUCLEONS: Physics: *Jerome Isaac Friedman* (1930–), United States. Jerome Friedman shared the 1990 Nobel Prize in Physics with Henry Kendall and Richard Taylor.

> *The angular distributions of the scattering of electrons from point sources (**partons**, which are related to gluons and quarks) match the characteristics of Murray Gel-Mann's hypothetical "quarks."*

Experiments that Friedman conducted at Massachusetts Institute of Technology (MIT) with other colleagues demonstrated that protons that were struck with sufficient energy by deflected electrons were scattered at wide angles. These, as well as other factors resulting from the experiment, verified the nature of the hypothetical quarks. Friedman and other scientists, using the laboratory at the Stanford Linear Accelerator Center (SLAC) in California, as well as the equipment at MIT between the years 1967 and 1975, detected the scattering of electrons from the protons and neutrons. This provided the first evidence of the quark internal structure of nucleons (the particles within the nucleus, i.e., protons and neutrons).

Quarks are a particular type of tiny "bits" of energy or particulate matter that compose the **protons** and **neutrons** of the nucleus of atoms. Note: Baryons (heavy) are three-quark groups that compose protons and neutrons, that when considered together, are called nucleons. Protons and neutrons make up the mass of the nuclei of atoms. They have about the same mass. Each has ½ spin, and they can be transformed into each other by giving up or receiving beta particles. Each proton and neutron consists of three quarks. Protons and neutrons are considered stable baryons (*see* Figure F10).

Six types of quarks have been identified and are usually referred to in terms of "pairs," as follows: 1) up and down quarks, 2) top and bottom quarks, and 3) charm

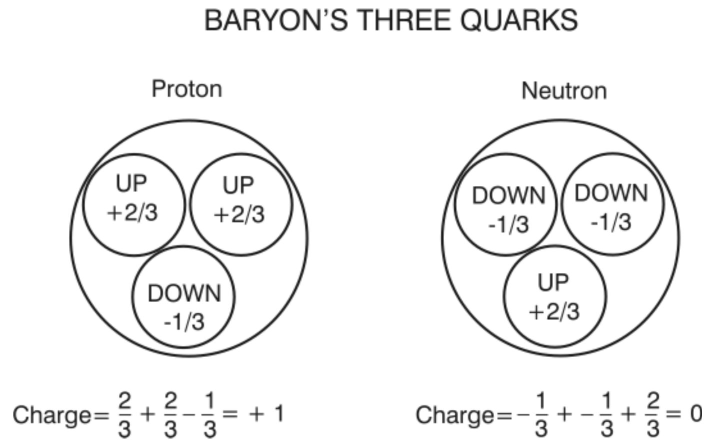


Figure F10. Quarks are bits of matter that compose the proton (with a +1 charge in an atom's nucleus) and neutrons (with a 0 charge, also found in an atom's nucleus). Together they make up most of the mass of the nuclei of all atoms.

and strange quarks. (Who says physicists don't have a sense of humor?) Protons consist of two "up" quarks and one "down" quark, while neutrons consist of two "down" quarks and one "up" quark. Unlike the proton with a +1 charge or a neutron with a 0 charge, quarks come with fractional electric charges as integers ranging from +1 to −1. There are several other "heavy" particles besides proton and neutrons that are composed of quarks. One example is the meson. Quarks are forever bound up inside the heavier particles found in the atoms' nuclei and are not found in a "free" state outside of the heavy subnuclear particles. There is some evidence that "mystery" particles called "gluons" are also found in the atoms nuclei. Their role is to hold together all the quarks found in the nuclei—thus the name "gluon." Otherwise all the positively charged protons would repel each other and the nuclei would come apart or just not exist.

See also Gell-Mann; Feynman

FRIEDMANN'S THEORY OF AN EXPANDING UNIVERSE: Astronomy: *Aleksandr Alexandrovich Friedmann* (1888–1925), Russia.

> *In opposition to Einstein's theory of a finite volume of an unchanging universe with a ''saddle'' shape, Friedmann's theory postulated a changing, and expanding universe with possible curvatures that may be zero, negative, or positive.*

Alesksandr Friedmann was educated at the University of Saint Petersburg in Russia where he received a degree in applied and pure mathematics in 1913. He became a manager in an aviation machine shop and later taught mechanics during World War I. After the war he began his career as an astronomer at the Pavlovsk Observatory in Saint Petersburg. He first became known for his work in the physics of the atmosphere and meteorology. He is best known for a paper he wrote in 1922 on his theory for the expanding, growing, changing universe.

His theory grew out of Einstein's theory of relativity to explain cosmology. Einstein's theory stated that the density is constant and thus must have a curvature. In other words, the universe did not change over time and had a limited volume. Friedmann came up with the idea of a universe of unlimited volume and a model of one that would change over time. Contrary to Einstein's theory, Friedmann considered the universe to be isotropic which means that all points in the universe move in all directions at the same rate. Therefore, the average density and size of the universe will change over time. The significance of Friedman's theory is that it later led to the big bang theory as an explanation for the creation and evolution of the universe.

Friedmann is also credited with coming up with different models for the shapes of the cosmos. Einstein proposed a "saddle" shape for the universe, while Friedmann claimed that different cosmological models would result in the curvature of space being either zero, positive, or negative. These various types of models for the universe are known as "Friedmann universes." Today, the theory of an expanding universe is accepted by most cosmologists based on evidence of rapidly receding galaxies, the "red-shift," and the rapid expansion of the universe since the big bang, rendering Einstein's "closed" universe theory less likely.

See also Dicke; Einstein; Gamow; Hale; Hubble; Lemaître

FRISCH'S THEORY OF A CHAIN REACTION: Physics: *Otto Robert Frisch* (1904–1979), England.

> *A sustainable nuclear chain reaction can be obtained by using just a few pounds of fissionable isotopes of uranium-235.*

In the late 1930s, Otto Frisch was involved in research with other scientists who discovered that uranium would decay into lighter elements when bombarded with slow neutrons. This work was confirmed and called *nuclear fission*, which was seen as a process capable of producing large amounts of energy. Frisch and Rudolf Peierls determined the rare U-235 was more likely to fission than other isotopes of uranium, such as heavier isotope U-238. Their additional calculations determined it would take only a few pounds of U-235 to reach a critical mass that would produce a sustainable chain reaction resulting in a massive explosion. This made the production of the atomic bomb a practical reality. Otto Frisch moved to the United States in the early 1940s to work on the atomic bomb project at Los Alamos, New Mexico.

See also Bohr; Hahn; Meitner; Peierls; Teller; Ulam

G

GABOR'S THEORY OF REPRODUCING THREE-DIMENSIONAL IMAGES: Physics: *Dennis Gabor* (1900–1979), England. Dennis Gabor (born Gábor Dénes in Budapest) was awarded the Nobel Prize in Physics in 1971.

> *A coherent light source will produce a two-dimensional holograph image that appears as a three-dimensional object on a photographic plate.*

Dennis Gabor was educated in Hungary and Germany followed by a career as a research engineer with Siemens & Halske AG, an electrical engineering company headquartered in Munich. One of his first inventions was the high-pressure mercury vapor lamp that is used for street lighting all over the world. With the rise of Adolph Hitler in 1933, Gabor left Germany. After a short period in Hungary, he moved to England where he found employment with the BTH (British Thomson-Houston) Research Laboratory in Rugby in 1934. In 1949 he joined the Imperial College of Science and Technology in London, eventually becoming a professor of applied electron physics until his retirement in 1967. Gabor always explained his work as "research serendipity" because his discoveries were based on previous research of other scientists, and much of the new information he reported grew out of their ideas.

He worked on improving the electron microscope that has a higher power of resolution than the light microscope but requires "light" with shorter wavelengths to be useful in observing things, such as the structure of crystals. To improve the image, Gabor used a method of positioning the light wave's cycle and intensity to build a fuller image of the objects being viewed by the electron microscope. He worked with micrographs produced by the electron microscope using coherent light, which is light that consists of wavelengths (frequencies) where the frequencies were exactly in phase and exhibited the same intensities. Therefore, because the light was of the same wavelength, it was a single pure color. He named the process *hologram* which is derived from the Greek words *holos* meaning "whole" and *gamma* meaning "message." The hologram expressed the idea that the resulting image contained "all" the information about the object being viewed. He used the mercury vapor lamp as the source of the coherent light even though it does not exhibit a high degree of coherent light (light of a single frequency or color).

Gabor learned of the work of the French physicist Gabriel Lippmann (1845–1921) who experimented with methods of recording the colors of nature so they could be reproduced more realistically than was possible with black-and-white film. In other words, Lippmann experimented with coherent light waves, as did Gabor, but merely to improve the technique of color photography. Gabor's work enabled the viewing of flat, two-dimensional photographs as three-dimensional images that acted somewhat like a stereoscopic image that stored all the information on the film, giving it a three-dimensional orientation. The problem of finding a pure single frequency light source was solved in 1960 when the laser was developed. Using a ruby crystal the laser produces a pure, intense, single frequency, coherent beam of red light that made the technique of holography a more common reality. In 1962 two engineering professors at the University of Michigan, Emmett Leith (1927–2005) and Juris Upatnieks (1936–), were the first to produce holograms that used laser light. Lasers have found many applications beyond the electron microscope, including side-reading radar, in the production of three-dimensional images that can be sent over wireless systems, laser light displays for entertainment purposes, and the all-important usage in various medical practices that have either replaced or surpassed standard surgical procedures.

GALEN'S THEORIES OF ANATOMY AND PHYSIOLOGY: Biology: *Galen* (c.130–200 BCE), Greece.

Galen's theory of the circulatory system: *The arteries and veins carry blood, not air, and the veins and arteries carry blood.*

Until Galen's time, Erasistratus' (c.300–260 BCE) theory that the essential body elements were "atoms" that were vitalized by air (*pneuma*) that circulated throughout the body by the arteries was accepted. Galen, one of the early experimenters who paid attention to his own observations, studied the structure and functions of organs and attempted to disprove this "air" theory. Experimenting with various small mammals, he discovered that blood, not air, flowed through the arteries. But Galen considered the liver to be the main organ of the circulatory system, and his theory stated blood was distributed to the outer parts of the body from the liver by the veins, and from the heart by the arteries. Galen also believed blood "seeped" through the intraventricular septum (central wall) of the heart through minute pores and that the heart had three chambers, each with its own function: the anterior or lateral ventricles (sensory information), the middle or third ventricle (cognition and integration), and the posterior chamber or fourth ventricle (memory and motor motion). He did not understand the role of the lungs in the circulatory system and believed the venous system (not the arteries) responsible for the distribution of food from the stomach to all parts of the body. Galen is considered by some historians to be the first to use the pulse of the heart as a diagnostic aid.

Galen's theory for the nervous system: *The brain controls the nervous system.*

Through the dissection of animals (never humans, except wounded gladiators), Galen demonstrated the distinction between sensory nerves (soft) and motor nerves (hard) and correctly placed the medulla as part of the brain rather than as part of the arteries. He correctly identified the nerves responsible for breathing and speech and demonstrated that specific nerves in the spinal cord control various muscles.

Galen's concept of the kidneys: *The kidneys, not the bladder, produce urine.*

Up to this time it was believed the bladder produced urine. By tying off the ureter, Galen proved the bladder did not produce urine but was merely a holding area for it. He also diagnosed several illnesses, including liver disease, by observing the urine of patients.

Galen's philosophy: *Nature does nothing in vain. God endowed every organ with a special purpose to perform special functions.*

Galen's philosophical outlook on nature was responsible for his success as a physician and scientist. He believed that the form of an organ was designed by a supreme being to perform a specific function, now known as "form follows function." Galen's medical knowledge and writings were accepted for over fifteen hundred years. Although his medical knowledge was advanced for this time in history, later physicians accepted his teaching without question and did little further investigating of the human body. Galen was the first to understand and use the pulse beat of the heart as a diagnostic aid. He proposed many theories concerning blood formation and flow, the nervous system, digestion, excretion, and so forth. His written works included over five hundred articles on his medical concepts that were translated by Arab scholars in the ninth century and later used during the Renaissance period in Europe that became the basis of medical theories and practices until the sixteenth century. This is why many historians believe that this respect for Galen's authority (the so-called tyranny of Galen) impeded medical progress for several centuries.

Although eclectic in his acceptance of the doctrines of earlier philosophers, Galen's main beliefs were based on the humoral pathology of Hippocrates (c.460–377 BCE) and Aristotle. For example, he based his theory of circulation on a three-part system of the liver, heart, and brain, each with its own spirits: natural, vital, and animal. His concept of preventive medicine was based on hygiene as well as "critical days" that were days when treatment would be more successful. He believed prevention was better than treatment and thought that diseases could be prevented if the "critical" days were observed. He was an excellent diagnostician for his era and was able to discern the source of many complaints. In addition to prescribing many different types of drugs, he used cold to treat hot diseases, and hot to treat cold diseases, and often used bleeding, purges, and enemas.

See also Hippocrates; Townes

GALILEO'S THEORIES: Physics: *Galileo Galilei* (1564–1642), Italy.

Galileo's theory of falling bodies: *Discounting air resistance, two bodies of different sizes and weights will fall at the same rate. Both will increase in speed of descent and land at the same time.*

From the time of Aristotle, it was believed a force could not act on a body from a distance. In other words, for an object to continue to move something physical needed to continue to push it; otherwise its movement would cease. In addition, Aristotle and others believed a body of greater weight would fall faster than a body of lesser weight, but they had never experimented with bodies heavy enough to overcome air resistance. Very light objects, such as a feather, would descend more slowly than would a rock, which seemed proof enough. It is most likely a myth that Galileo dropped objects of different weights from the Leaning Tower of Pisa. It may have been the Flemish mathematician and engineer Simon Stevin (1548–1620), not Galileo, who first dropped two rocks of different weights simultaneously from the Tower of Pisa to determine if they would land at the same time.

What we do know is that Galileo contrived his method of using an inclined plane made from a long wooden board to make accurate measurements and arrive at a reasonable explanation for the phenomenon of free-falling objects. We also know that he could not have dropped the balls from the Leaning Tower of Pisa because his inclined plane experiment was conducted while he was living in the town of Padua, not Pisa. Galileo assembled an inclined plane that allowed two balls of different weights to roll slowly down the incline, which enabled him to measure their rates of descent by using the pulse of his heartbeat. The only other timing devices available at that time were sundials, time candles, and dripping water clocks. None was accurate enough for Galileo's purposes. He also ensured that the balls were of sufficient, but of different weights so the resistance of air or the surface of the wooden planks of the inclined plane would minimally affect them. His measurements confirmed that not only did the balls roll down to the bottom of the plank in equal time, but also their rates of descent increased as they passed equally spaced marks on the planks. When he experimented with planks raised higher and lower to form different degrees of inclination, he discovered an interesting factor: No matter at what angle the planks were positioned, the balls covered a single unit of distance on the plank for the first unit of time based on his heartbeat and a water clock that used a slow dripping stream of water. But for the second unit of time, the balls rolled three times faster than the first unit's distance. He discovered that the ratio of distances covered by the balls increases by odd numbers. This means that for the total time of descent of four seconds, the balls covered a distance sixteen times greater than is covered in one second. This relationship of the ratio between time and distance is further explained as acceleration acting uniformly on a falling body, where the descending distance covered is directly proportional to the square of the time (*see* Figure G1).

From these data, Galileo formulated the law that states $s = \frac{1}{2} at^2$, where s is the distance the ball travels, a is the acceleration, and t is the time lapsing of the ball's descent. Galileo's experimental results illustrated the uniform accelerating force of gravity, which Sir Isaac Newton later developed as part of his concept of inertia and

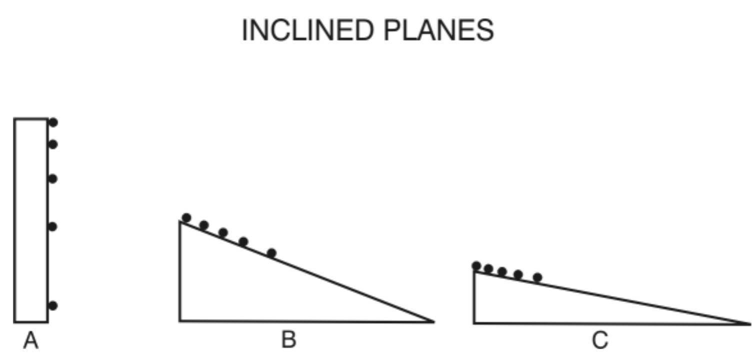


Figure G1. The balls represent the ratio of the distance of their descent to the square of the time of their descent.

the three laws of motion. The other consequence of this experiment was that Galileo was now able to correct the Aristotelian idea that the push of "angles" was required to maintain planetary motion. Once friction was removed from consideration, the constant pull of the sun's gravity sustains the planets' orbiting the sun.

An interesting bit of modern history: During the 1991 Apollo 15 moon landing, astronaut David Scott dropped a feather and hammer at the same time, and they hit the surface of the moon at the same time. Apparently he wanted to prove that Galileo was correct. The same experiment with a feather and rock can be performed on Earth within a large vacuum chamber where most of the air has been removed.

Galileo's concept of the pendulum: *The square of the period (oscillation) of a pendulum varies directly with the length of it suspending string.*

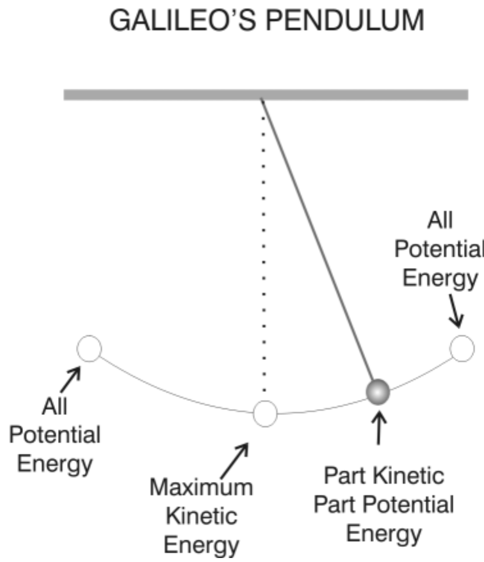


Figure G2. A typical pendulum as used by Galileo to establish his theory of pendulums.

While studying medicine at the University of Pisa, a youthful Galileo was attending church services in the town's cathedral when he noticed that a large chandelier swayed in the breeze. Sometimes the chandelier swayed in longer arcs and sometimes in smaller arcs; the time period of the swing seemingly was the same regardless of the sweep of the chandelier. The pulse of his own heartbeat that he used to count the time that lapsed for each swing provided him with an idea for an experiment. Upon returning home, he designed a pendulum with a bob on a short string and another bob of a different weight on a longer string (*see* Figure G2).

Again timing them with his pulse, he confirmed his theory. He summarized his ideas as follows: 1) Air resistance (friction) prevents the pendulum from returning to its exact starting position. However, if there is no air resistance, the bob will always return to its original position. Thus, sooner or later, all pendulums come to rest. Pendulums with lighter bobs come to rest sooner than those with heavy bobs. 2) The period of swing or sweep of the pendulum is not related to the weight of the bob. 3) The time period for each sweep of a pendulum is not dependent on the length of its sweep (this observation was later proved incorrect). 4) The square of the period for a pendulum is directly proportional to the length of the pendulum.

Once set in motion, a pendulum oscillates with a constant frequency that is inversely proportional to the length of its string. Although Galileo recognized the importance of this phenomenon, he was unable to develop

Figure G3. An artist's depiction of Galileo's air thermometer.

his pendulum into a practical timepiece (he continued to use a water clock and his pulse). However, it became an important concept in the design of accurate clocks. Some years later, Christian Huygens fabricated a workable pendulum clock similar to a grandfather's clock that used weights to maintain the movement of the pendulum (*see also* Huygens).

Galileo's concept for the measurement of temperature: *There is a direct relationship between the temperatures of air and water and their volumes.*

From the beginning of time, people understood the concepts of hot and cold, but until Galileo, there was no objective way to measure the exact temperature for either. Galileo devised an air thermometer, or thermoscope, a crude, and not very accurate, instrument for measuring temperature. He used a long, thin, stalk-like tube of glass, open at one end and with a closed bulb at the other end. Placing his hands on the bulb until it was warm; he then inverted the open tube into a pan of water. As the bulb cooled, some water was drawn up in the narrow tube toward the bulb. Also, as the temperature of the surrounding air changed, so did the level of water in the tube. This furnished Galileo the means to measure the level of water in the tube and to make some calculations (*see* Figure G3).

His instrument, however, was quite inaccurate due to the effects of atmospheric pressure on the water in the pan, which was open to the air. Even so, this was the first thermometer, which Galileo later redesigned. He enclosed the water in a sealed tube containing "floats" constructed of small, hollow glass balls adjusted for different water densities. As the temperature changed, so would the density of the water, causing one or more balls to rise or fall, thus indicating the air temperature. Today these fascinating instruments are sometimes referred to as *thermometro lentos* (*see* Figure G4).

Figure G4. A modern version of Galileo's Thermometro Lento.

Galileo's astronomy theories: *1) Dark ''spots'' on the surface of the sun appear to move around the sun; therefore the sun must rotate, and so must Earth and other planets revolve around the sun. 2) Jupiter has several of its own moons similar to Earth's moon. 3) Saturn has bulges on its side as well as its own moons. 4) The Milky Way is composed of a multitude of stars clustered together.*

The telescopes that Galileo constructed enabled him to view objects never before seen by humans, and thus he conceived many theories about the planets and stars. The credit for the development of the first telescope is usually attributed to either of two Dutch spectacle makers, Hans Lippershey (1570–1619) or Zacharias Janssen (1580–1638). Janssen is also credited with inventing the microscope in 1608. Galileo learned of this "secret" device and then constructed his own telescope. An excellent lens maker, he improved the curvature of his lenses to reduce optical aberration. Galileo built three telescopes, the last of which was improved to approximately 30-power, or about the power of a good pair of modern binoculars.

One of Galileo's first telescopic viewings was of the surface of the sun, where he observed the movement of darker areas or "spots" and concluded the sun must be rotating. Based on knowledge of moving bodies, he surmised the planets and Earth are not only spinning on their axes, but are also revolving about the sun in circular paths. This was the first confirmation of the Copernican heliocentric concept of the solar system. (See Figure G5.)

Galileo disagreed with, or ignored, Kepler's laws that state that planets move in ellipses. Because the concept of gravity was unknown in his time, Galileo believed the paths of planets were based on inertial circular movement. This erroneous concept prevented him from completely developing his law of uniform acceleration into the Newtonian-type laws of motion (*see also* Copernicus; Kepler; Newton).

Using the telescope he constructed, Galileo observed two tiny objects that appeared to move around the planet Jupiter, and he tracked and recorded the changes in their position. Later he discovered two other moons of Jupiter, for a total of four larger moons. (A total of sixteen satellites of Jupiter have been subsequently discovered.) His records of the eclipses of Jupiter's satellites aided sailors in determining longitudes at sea.

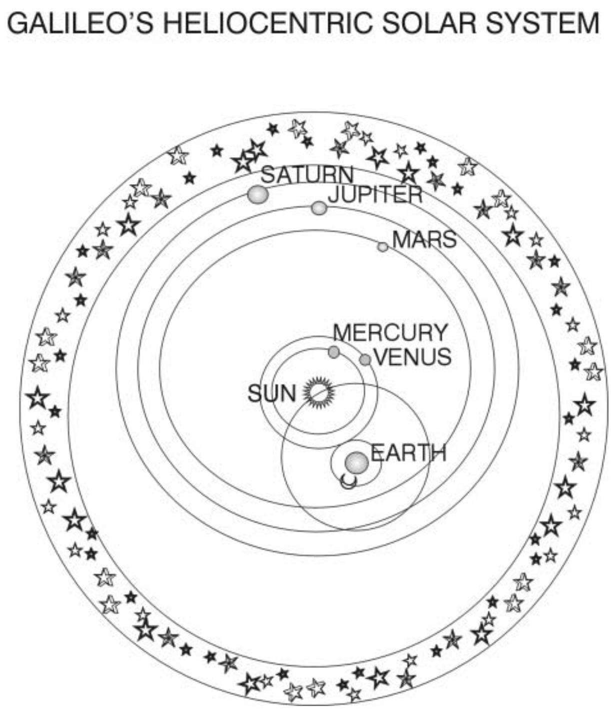


Figure G5. Galileo's heliocentric solar system was the first confirmation of Copernicus' original concept of a sun-centered solar system.

After viewing Saturn at different times, Galileo noticed "bulges" on each side of the planet that periodically became larger, then smaller. His telescope was not powerful enough to resolve these "bulges" into the many rings around the planet that change their apparent shape as the orientation of the planet changes when viewed from Earth. Galileo also identified several of Saturn's moons.

Always fascinated by the multitude of stars that could be seen with his telescope, Galileo observed that, when aiming it at the Milky Way, it became obvious that this huge area of the sky was composed of many millions of stars. He recorded there were more stars, some very faint, in this area of the sky than in all the other areas combined. Up until this time, the Milky Way was considered to be just a large cloud in the sky.

Although Galileo did not completely understand gravity or inertia, he had a firm concept of the mechanics of force, and his theories concerning falling bodies were a forerunner to Newton's three laws of motion. His "thermoscope" was a precursor to more accurate instruments for temperature and pressure measurements, including the modern mercury thermometers and barometers.

His work with fluid equilibrium, as in a working siphon, led to a new concept of pumps. At one time it was believed that by reducing the air pressure above water, the water would be "sucked up" into the pump (similar to a drinking straw). Galileo understood that normal air pressure outside the pump "pushed" the water up into the pump

Most likely Galileo will be remembered for his theory that challenged Ptolemy's Earth-centered universe concept, which was then accepted by the Church of Rome. Because of his belief in the theory of a Copernican sun-centered system, Galileo was secretly denounced to the Inquisition for blasphemous utterances. He was later forced to recant and was sentenced to house arrest until his death at age seventy-eight. Near the end of the twentieth century, the Roman Catholic Church removed the charges and exonerated Galileo.

Galileo was one of the first persons to make a distinction between religious beliefs related to the physical world and the results of experimental evidence related to the nature of the universe. Even today, there continue to be misunderstandings between religious beliefs based on faith and those related to the nature of the universe that are based on experiments and factual evidence.

to the area of reduced air pressure (just as normal air pressure "pushes" the liquid up a straw used for drinking).

He also developed the mathematics that explained the flotation of solids in liquids and studied the magnetism of lodestones that would influence later scientists such as William Gilbert. Galileo was the first to demonstrate that a magnet broken into smaller pieces retained its magnetic properties because each piece, no matter how small, is still a magnet with its own north and south poles.

Galileo, along with Janssen, is credited with developing the first practical microscope after adapting his concept of a telescope to produce a crude but workable microscope. In addition, he tried to measure the speed of light by flashing a lantern positioned on one hill to an assistant who flashed his lantern back from another hill. Although he could not detect the speed of light, nevertheless he was convinced that light travels with great and measurable speed.

At six-month periods, as Earth revolved around the sun, Galileo attempted to measure the parallax of stars to determine their distance from Earth. Although his instruments were not accurate enough to accomplish the task, his concept was correct because he used parallax to measure the distance of the moon to Earth.

See also Copernicus; Fahrenheit; Gilbert; Kepler; Newton; Ptolemy

GALLO'S HIV-AIDS THEORY: Biology: *Robert Charles Gallo* (1937–), United States.

The HTLV-3 retrovirus suppresses the immune system lymphocytes, thus causing acquired immune deficiency syndrome (AIDS).

Robert Gallo was familiar with the process of how, when under attack, the body's immune system produces interleukin-2, which stimulates special lymphocytes identified as T-cells to fight viral infections in leukemia patents. In the early 1980s he surmised a virus was responsible for a similar suppression of the immune system that led to opportunistic (AIDS) infections. Gallo then hypothesized the retrovirus he identified as HTLV-3 was reacting with the immune system in a similar manner as it did for the blood cancer disease leukemia. At the same time, Luc Montagnier, the French virologist and researcher, made a similar deduction and in 1983 sent Gallo a sample of his virus, which he called lymphadenopathy associated virus (LAV). Gallo's assistant discovered a particular T-cell type that could be invaded but not killed by these viruses, which then could be used to develop a test for the virus in AIDS patients. Gallo proceeded to secure a patent for his new AIDS test. This resulted in an international argument about the discovery of the AIDS virus because the American HTLV-3 and French LAV viruses were the same. It was also claimed that the French LAV virus was used in Gallo's laboratory to develop the test. It was settled in 1986 when Gallo and Montagnier agreed that both their names would appear on the patent document and 80% of all royalties would be given to an AIDS research foundation. The HTLV-3 and LAV virus were renamed the HIV virus by an international committee. Between 1981 and 1990 Gallo published over four hundred papers related to his research on HIV/AIDS.

See also Baltimore; Montagnier

Recently, several scientists have claimed that a vaccine for the HIV virus can be developed. In 1997 Dr. Robert Gallo, now the head of the Institute of Human Virology at the University of Maryland's Baltimore campus, questioned the possibility of developing such a vaccine. His concerns are related to the pathogenesis of the HIV virus, including the large number strains of the HIV virus, the lack of good animal models for testing the vaccine, and the fact that the HIV virus invades basic DNA cells of the immune system. In addition, for such a vaccine to be effective, it must be the only viable vaccine in the patients' bodies. Since then, several experimental vaccines have been tested but to date none seem to be 100% effective.

More recently it was reported in the September 22, 2007, issue of the *New York Times* of the failure of AIDS vaccine tests. "A much-heralded H.I.V. vaccine has failed to work in a large clinical trial, dealing another serious setback to efforts to stop the AIDS epidemic." Despite this failure, efforts continue to develop an effective AIDS vaccine, although researchers acknowledge that the quest will be difficult and in all likelihood not viable in the foreseeable future. There is continuing debate about how to eradicate HIV infections and AIDS from the human population. Although this disease is preventable and somewhat predictable, human nature is not.

GALTON'S THEORY OF EUGENICS: Biology: *Sir Francis Galton* (1822–1911), England.

> *The human race can be improved by selective and controlled breeding, as is done with domesticated plants and animals.*

As an anthropologist, Francis Galton's extensive travels enabled him to observe varied cultures and races and subsequently to conduct research in the areas of human heredity. Galton knew that since the beginning of farming, humans selected not only the best grains as seeds to plant, but also selected animals with the most desired characteristics to breed, therefore, improving the quality and quantity of agricultural products, just as can be done today with genetic engineering. He was also aware of the theory of organic evolution proposed by his cousin, Charles Darwin. Based on this background, Galton considered controlled breeding a means to improve the human species just as it had for many species of plants and animals. Galton is credited with coining the term "eugenics," meaning "good genes" or "good breeding." The first to study identical twins, he discovered that though identical twins have similar patterns of whorls and ridges in their fingerprints, there are just as many differences. In other words, everyone's fingerprints are unique. He also developed the first system for classifying and identifying fingerprints, which expanded the field of **forensic** science. Using his research on identical twins, he attempted to resolve the distinction between environmental versus inherited factors that influence intelligence. His research, the premise of which was to determine what is most important in the development of intelligence—nature or nurture—continues today. Evidence indicates that nature may be responsible for over 50%

> The ''science'' of eugenics has a checkered reputation due to the moral and ethical implications of controlling the selection of who shall be born into the world. Many people associate and relate eugenics with the Nazis' program for developing a ''super race'' during the 1930s and early 1940s. Today, ''ethnic cleansing'' might also be an application of eugenics. Even so, there are instances where forms of eugenics are used today without that stigma. When a couple (the husband is infertile) who wants to have children select frozen sperm for fertilizing the wife's eggs, they may have the option of selecting the physical characteristics of the sperm donor. The same type of selection can be made when deciding on the implantation of a **zygote** into the womb of a female. Another example is **amniocentesis** that is used to determine the genetic health of a fetus, and thus this information can be used to make the decision to abort or continue the pregnancy. Another more negative example is the use of ultrasound to specifically determine the sex of the unborn child that may lead to the abortion of a child of the ''wrong'' sex. On a more subtle level, when men and women—consciously or unconsciously—select a mate, they are ''discriminating'' as to how that mate should look and behave to make a good parent.

of a person's intelligence, but environmental factors during gestation and after birth are also important to the development of intelligence. Galton was the first to use new quantitative methods for eugenics research, including statistical correlation coefficient and regression analysis (statistical methods for comparing similarities between variables). His 1888 statistical techniques were sound but somewhat inadequate as compared to the statistics used for data analysis today. Although Mendel's work with genetics was not yet "rediscovered," Galton's research indicates an understanding of its basic principles. His methods were used mainly for analyzing the results of experimental medical research. His invention of correlation coefficient is probably more important than his work on eugenics. Interestingly, Galton's research led to the development of fingerprinting based on the unique swirl patterns for each individual's fingertips that are used for identifying individuals.

See also Darwin; Mendel; Wallace

GALVANI'S THEORIES OF GALVANIZATION AND ANIMAL TISSUE ELECTRICITY: Physics: *Luigi Galvani* (1737–1798), Italy.

Galvani's theory of galvanization: *Small electrical currents can be used to ''coat'' metals that are easily oxidized (iron rust) with other metals that resist oxidation (zinc).*

Although Galvani was trained in medicine/anatomy and experimented with electrophysiology, he was honored for his discovery of the galvanization process. He called his discovery the *metallic arc* because it used an electric current to bind a coating of zinc to iron. Galvani's process is similar to electroplating of metallic and nonmetallic items. Today, galvanized iron or steel also can be produced by dipping the item made of iron into a hot bath of molten zinc or by "spraying" very small zinc particles onto hot iron or steel. The resulting iron products will be more rust resistant than nongalvanized metal.

Andre Ampère named the *galvanometer*, an instrument used to measure small electric currents, after Galvani who is also credited with the discovery of current electricity. Galvani pursued his work with electric currents to include investigating whether animal nerves carry electricity.

Galvani's theory of animal tissue electricity: *Electricity is present in animal tissue that can be discharged when in contact with two different metals.*

Luigi Galvani's electrophysiology experiments involved the touching of a dissected frog's leg with a spark from a machine that produced static electricity. However, he made a famous experimental error with regard to animal tissue electricity. During a thunderstorm, Galvani clamped onto an iron railing the brass hooks that he inserted into a dissected frog's spinal cord. The frog's muscles twitched, as they did also when two different types of metals touched the spinal cord. He incorrectly concluded that the electricity was generated by the frog's tissue, while rejecting the possibility that the electricity that caused the twitching came from another source. Later, Alessandro Volta demonstrated that the electricity was not derived from the tissue but rather from the brass and iron coming into contact with each other under moist conditions.

See also Ampère; Franklin (Benjamin); Ohm; Volta, Watson (William)

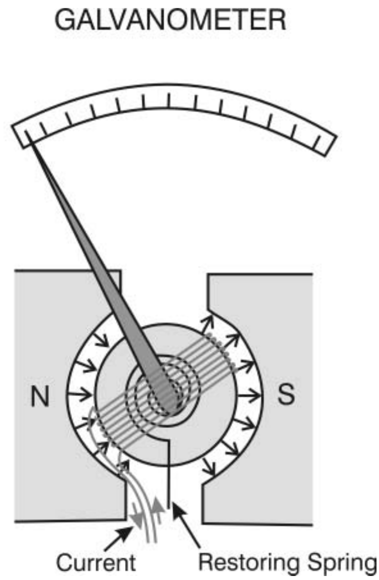


Figure G6. Andre Ampère named the *Galvanometer* after Luigi Galvani. It is used to measure small amounts of current electricity.

GAMOW'S THEORIES OF THE UNIVERSE AND DNA: Physics: *George Gamow* (1904–1968), United States.

Gamow's big bang theory: *The universe was created more than fourteen billion years ago from a single point source in space and time.*

Many civilizations over many generations theorized that the genesis of the universe was based on the egg or seed concept, where everything "grew" from a minute and rudimentary source. Also, persistent through the ages are religious concepts for the origin of Earth and/or the universe. The big bang theory proposes that an incredible singularity event occurred where a dense point or source of energy "exploded" and rapidly expanded in all directions in microfractions of a second, to form all the energy and matter in the known universe. There are several current theories for the creation, nature of, and demise of the universe—the static universe, the ever-expanding universe, the regeneration concepts, and the possibility of multi-universes of which ours is just one of many. Many scientists proposed theories similar to the big bang for an expanding universe that they based on Einstein's theory of relativity, despite the fact that Einstein proposed a static universe as evidenced by the "saddle-shape" for his unchanging universe. In 1948 Sir Fred Hoyle proposed that matter was continually generated by existing matter and is continually spread throughout the expanding universe. This is considered the model that George Gamow used to revise earlier theories and advance another based on mathematical concepts. Gamow believed there was evidence not only of an expanding universe but also that if the universe is continuing to expand, it must have had a beginning. In other words, if the universe is forever expanding in all directions, then it must have started at a central point from something extremely small that contained all the energy and matter required to form it, more recently referred to as a "**singularity**." As evidence to substantiate his big bang theory, Gamow answered Olbers' paradox, which raised the question of why the sky of the universe appears dark rather than full of light, as does the area illuminated by our sun. Gamow explored several possible answers to this paradox but felt the best is that the universe is ever

George Gamow was educated at the University of Leningrad where he received his PhD in 1928. He spent time in Copenhagen, Denmark, and Cambridge, England, before moving to the United States in 1934. He was a professor of physics at George Washington University and later at the University of Colorado. He had wide research interests, including a later interest in molecular biology. In addition to his work with the big bang theory, he determined that the heavier elements were all formed in the hot thermonuclear interior of the stars. He also demonstrated how our sun is warming, not cooling, which may account for the cyclic nature of Earth's cool and warm periods. The sun's temperature cycles may partially account for today's slight warming of Earth's oceans and atmosphere. George Gamow was well known and respected not only as a physicist/cosmologist and microbiologist but also as a popular science writer. He was the author of several excellent easy-to-read books on modern physics that are still in print.

expanding. Thus, stars cannot shine enough light to fill up all that space because their radiation is not in equilibrium with their surfaces. One of the main factors supporting an expanding universe and opposing a static universe is that a self-contained, nonexpanding universe is incapable of disposing of the energy produced by all the stars that would result in a very hot static universe, whereas an ever-expanding universe would ultimately reach a balance for star energy. Thus, **equilibrium** would be established and a stable temperature would exist, or there possibly could be a decrease in overall temperature. According to the second law of thermodynamics (entropy), the final temperature would be absolute zero, and an absolute equilibrium would exist. George Gamow calculated that the leftover uniform background radiation from the big bang explosion is equal to about 5 kelvin. In 1964 two AT&T scientists Arno Penzias and Robert Woodrow Wilson (1936–) discovered this "leftover" energy by detecting the **primordial** microwave type radiation. This discovery is the best current evidence for the big bang theory. Even so there are new theories that may lead to a reconsideration of an infinite universe; that an ever-expanding universe is an illusion, and that it is finite after all (*see also* Doppler; Hale; Hubble; Lemaître).

Gamow's theory for the beginning of life: *The amino acids, which form proteins, are constructed from the four nucleic acid bases of DNA.*

George Gamow based his theory for life on Francis Crick's and James Watson's proposed structure of the DNA double helix. The nucleic acid–based pairs connecting the two sides of the double helix are the nucleotides of adenine plus thymine (A + T) and guanine plus cytosine (G + C). Gamow realized this sequence of codes for these four nucleotides (A, T, G, and C) could produce only four amino acids, not the twenty or more existing in humans, and thus would be inadequate to produce the multitude of proteins necessary for life. Therefore, he concluded there needed to be at least three sequences of the base pairs present to produce codes necessary for the required number of amino acids. Using this code of the nucleotides, at least sixty-four amino acids could be produced ($4 \times 4 \times 4 = 64$). Gamow's mathematical code explained the sequencing required for amino acids to produce proteins.

Gamow's theory of the living cell: *Cells in plants and animals are structured to carry out functions analogous to those processes and procedures related to running a factory.*

George Gamow used the analogy of an industrial factory to explain the functioning of a living cell. The manager's office represents the nucleus of the cell, whereas the chromosomes are the file cabinets where information, production plans, and diagrams are stored. When a new cell (factory) is to be opened, the secretary and staff produce an exact copy of what is in the file cabinets. As the new factory grows, a new manager's office takes over, and the process is repeated. The "workers" and "machinery" of the factory are abundant and represent the enzymes, protoplasm, and other cell components. The chromosomes and their genes, which are stored in the file cabinets, are very limited but can be used to replicate the factory and start all over.

See also Crick; Einstein

GARROD'S THEORY OF CONGENITAL METABOLIC DISORDERS: Biology and Medicine: *Sir Archibald Edward Garrod* (1857–1936), England.

> *The rare metabolic disorder* alkaptonuria *is not a bacterial infection of the urinary system but rather a genetic defect related to the lack of an enzyme in the chemical breakdown of a crucial protein.*

Alkaptonuria is an uncommon disorder where urine turns dark brown when exposed to air. At first it was thought to be due to a bacterial infection, but Garrod demonstrated that it was a genetic disorder—not a disease caused by bacteria. This genetic condition is rare in the general public but is common in the offspring of first-cousin marriages. Garrod demonstrated that alkaptonuria followed the pattern explained by inheritance of recessive genes as described by Mendelian genetics.

Archibald Garrod, an English physician who discovered the nature of several congenital metabolic disorders, determined that the condition of alkaptonuria was due to the presence of large amounts of homogentisic acid (also known as alkapton) that is excreted in the urine due to a deficiency of several amino acids. In other words, Garrod, who was exploring the field of biochemistry, understood that this condition was due to the lack of an enzyme responsible for the breakdown of a protein that resulted in the buildup of the chemical that darkens the urine.

Garrod was fifty years ahead of his contemporary biochemists' understanding of the implications of this theory for the genetic nature of metabolic disorders. Although the conditions of alkaptonuria (dark urine) are visible, not all metabolic disorders are that obvious. Garrod wrote about and gave lectures about these conditions that he referred to as "inborn errors of metabolism." His belief that genetics was involved in the process was evident when he wrote that there are many variations in humans that are determined by genetics, and that no two individuals are alike either chemically, biologically, or structurally. Garrod identified several other congenital metabolic disorders including *cystinuria* (an inborn defect involving an excess secretion of several amino acids), *pentosuria* (a congenital urinary defect in the oxidation of glucuronic acid that is a condition principally in those of Jewish heritage), and porphyria (a form of inherited insanity that caused the English King George III's illness).

GASSENDI'S THEORIES: Physics: *Pierre Gassendi* (1592–1655), France.

Gassendi's atomic theory: *God created the atoms as immaterial souls that could exist and interact in a void. He then gave them to man.*

Believing that atoms could exist only in a void in which the tiny particles could interact with each other and religious spirits, Gassendi tried to make the atomism of Lucretius, Epicurus, and Democritus agreeable with Christianity, but he opposed

In 1624 the Paris Parliament passed an ordinance declaring that any person would be put to death if he taught or held any doctrine opposed to Aristotle. In spite of this law, Gassendi published his *Dissertations against Aristotle* which attacked many of the ideals and teachings of not only Aristotelianism, but also the many beliefs of scholasticism. Because he was a doctor of theology who was ordained in 1617 and later a professor of mathematics at the College Royal in Paris, he escaped punishment by the Parliament. His views on atomism were expressed in his *Observations on the Tenth Book of Diogenes Laertius* in which he insisted that atoms were created by God and that God created the void of space so atoms could exist and thus interact with each other. This concept was later expanded to a variety of theories related to the atomic and chemical nature of the universe (*see* Atomism Theories). Gassendi was interested in astronomy and recorded many viewings of eclipses, comets, and the planets. In his book *Mercury in the Face of the Sun* he recorded the first transit of Mercury that supported Johannes Kepler's theories on the motions of planets.

Aristotelianism regarding these matters. Gassendi's concept of a void was very much like the modern concept of the vacuum of space. He disagreed with Aristotle's belief that a void did not, and could not, exist. Gassendi was a believer in the Epicurean views of Lucretius' doctrine of atomism. Galileo, Robert Boyle, and later Isaac Newton, as well as other scientists, were influenced by Gassendi's "Epicureanism" philosophy. This corpuscular concept states that for atoms to exist, a vacuum must surround them. Thus, if the atoms were removed, only the vacuum would remain (*see also* Aristotle; Atomism Theories; Boyle).

Gassendi's theories for falling bodies, sound, and astronomy: Pierre Gassendi, an early philosopher, propagated his ideas by incorporating his moderate skepticism with some experimentation that influenced his philosophy.

Gassendi was the first to test Galileo's contention that a ball dropped from the mast of a ship would fall at the base of the mast, not at some distance aft of the mast. Ancient sailors who dropped rigging tools could attest to this fact. Oddly, no empirical experiment had been conducted prior to Gassendi's.

It is also reported that Gassendi was one of the first to measure the speed of sound. It is unclear how he made his measurements, but it is assumed he fired a cannon while someone on a far hill at a known distance from the cannon timed the smoke pouring out the barrel until the sound was heard. His figure of 1,473 feet per second was about 50% greater than the current figure of 1,088 to 1,126 feet per second in dry air at sea level. The speed of sound depends on the density of the substance through which the sound is traveling. For example, sound travels at the speed of 4,820 feet per second in water, 11,500 feet per second in brass, and 16,500 feet per second in steel.

Gassendi studied **comets** and eclipses and recorded the first observed transit of Mercury in 1631. He was the first to describe as well as name the northern lights *the aurora borealis*.

See also Descartes; Galileo

GAUSS' MATHEMATICS AND ELECTROMAGNETISM THEOREMS: Mathematics: *Karl Friedrich Gauss* (1777–1855), Germany.

Gauss' theory of least squares: *A circle can be divided into a heptadecagon by using Euclidean geometry.*

Karl Gauss, a child prodigy in mathematics, was considered a "human calculator" who could solve all kinds of complicated problems in his head. Gauss demonstrated this seventeen-sided polygon (heptadecagon) could be drawn using only a compass, ruler, and pen. All seventeen sides were of equal length when laid on arcs of a circle. Earlier Greek mathematicians could never accomplish this exercise, which was considered an advancement in geometry. Gauss also demonstrated there were a limited number of polygons (many-sided figures) that could be constructed using these tools. An example of a polygon that cannot be so constructed is the heptagon (a seven-sided polygon) (*see also* Archimedes).

> The International System of Units (SI) for this flux density is called a *gauss* in his honor. In the SI, CGS units (using centimeters, grams, and seconds rather than MKS—meters, kilograms, and seconds), a unit area of 1 square centimeter with a flux density of 1 *maxwell* per square centimeter equals 1 *gauss*. The gauss is equal to 1 maxwell per square centimeter, or 10^{-4} *weber* per square meter or 10,000 gauss equals 1 weber. Gauss and Weber developed the magnetic-electric telegraph and a new instrument called the magnetometer. Magnetic field strength is rated in gauss units, an important concept for modern technology utilizing all types of magnets.

Gauss' theory of errors: *Successive observations and measurements made of the same event by the use of instruments are never identical, but their mean value can be calculated.*

This theory is related to probability. Gauss claimed that the distribution of errors for the **mean** differences of measurements by observations (particularly astronomical observations) is as accurate as the probability (odds) when throwing dice. This statistical technique has been, and still is, used by most scientists who make a series of measurements and calculate the means of these measurements. They can be reasonably certain that the difference between two means is a meaningful representation of their observational measurements. Gauss' work in statistical probability distributions is referred to as G*aussian* statistical distribution. This concept is used for the statistical treatment of data for most research experiments.

Gauss' theory of aggregates: *Properties of individual units of populations can be accurately observed and studied in large groups (aggregates).*

This is another theory used by most scientists and involves the study of large populations of particles, such as atoms, molecules, chromosomes, and genes. An example is Brownian motion, which is the observed movement of tiny microscopic particles of a solid, such as pollen, that is caused by molecular motion in solution. The concept of aggregates explains the kinetic theory of gases as well as the gene theory for inheritance. Although this theory is based on and accepted as an assumption, it does work (*see also* Ideal Gas Laws).

Gauss' law of the strength of electric and magnetic flux: *The greater the closeness (density) of the lines of force of an electric field (or magnetic field), the stronger the field.*

Gauss and the German physicist Wilhelm Weber (1804–1891) collaborated on studying the nature of electric and magnetic fields. They calculated the number of lines of force and the closeness of those lines, which determine the "flux density" representing the strength of the electric field. Electrical flux is a measure of the number of lines in an electric or magnetic field that passes through a given area. Gauss' law states the relationship between electrical charge and an electrical field. It is easy to picture by considering that the field is stronger if these lines of force are crowed together, and the field will be weaker if the lines of force are further apart. In some ways, his statement for the relationship between an electric charge and an electric field is another way to explain Coulomb's law.

See also Coulomb; Faraday; Maxwell; Weber

Gay-Lussac, a French engineer, physicist, chemist, and accomplished experimenter, made several other contributions to science. He collaborated with several other Frenchmen on a number of projects, including one where he used balloon flights for scientific purposes. In 1804 he and Jean-Baptiste Biot ascended 4 miles (about 7 km) in a balloon, the highest altitude attained by humans as of that date. They made the first high-altitude measurements of atmospheric pressure and Earth's magnetism. Gay-Lussac discovered the poison gas cyanide (HCN), and in 1815 he made cyanogen (C_2N_2), a toxic univalent radical used for the production of insecticides. His experiments with compound radicals were a precursor to the development of organic chemistry. Gay-Lussac and the French chemist Louis Jacques Thenard (1777–1857) produced small amounts of the reactive metals sodium and potassium. When Gay-Lussac mixed metallic potassium with another element, it exploded, wrecking his laboratory and temporarily blinding him. He also discovered a new **halogen** similar to chlorine. He named it *iode* (iodine), which means "violet."

GAY-LUSSAC'S LAW OF COMBINING VOLUMES: Chemistry: *Joseph-Louis Gay-Lussac* (1778–1850), France.

> *The volumes of gases that react with each other, or are produced in chemical reactions, are always expressed in ratios of small, whole numbers.*

An example: When one volume of nitrogen gas (N_2) is combined with three volumes of hydrogen gas ($3H_2$) the result will be exactly two volumes of the gaseous compound ammonia ($2NH_3$). Their respective volumes are the exact ratio 1:3:2. Gay-Lussac determined the existence of the law for combining volumes of gases, but he had no idea of why this law applied. An explanation had to wait until Amedeo Avogadro established the law explaining that equal volumes of all gases contain the same number of molecules (at the same temperatures and pressures), regardless of the physical and chemical properties of the gases.

In addition to the law of combining volumes, Gay-Lussac discovered that all gases expand equally when the temperature rises. This is a modification of Charles' law. Both of these gas laws, including Boyle's gas laws, are considered the *ideal gas laws* because they are really approximations. Gases exhibit only the relationships of P, T, and V (P = pressure, T = temperature, and V = volume) as expressed in the laws, at ordinary (moderate) temperatures. In 1808 Gay-Lussac published his law, usually called the law of combining gases, when referring to chemical reactions where the number of atoms is constant. This law confirmed the work of Dalton, who missed the importance of the relationship between temperature and volume of gases. In essence, the law states that for any gas, the temperature and pressure are directly related at a constant volume for that gas. The equation is $P/T = K$, where P is the pressure directly related to T, the temperature for K, a given constant (i.e., volume). Conversely, if the gas is heated, its volume increases as long as the pressure on the gas is constant; and if the pressure increases, so does the temperature of the gas for a given volume of a contained gas. Another way to state it is that the volume of gases expands equally when subjected to the same changes of temperature provided that the pressure remains the same.

See also Avogadro; Boyle; Charles; Ideal Gas Laws

GEIGER–NUTTER LAW (RULE) FOR DECAY OF RADIOACTIVE ISOTOPES: Physics: *Hans (Johannes) Wilhelm Geiger* (1882–1945), Germany.

> *There is a linear relationship between the logarithm of the strengths of alpha particles and the particles' rate of decay from their source nucleus.*

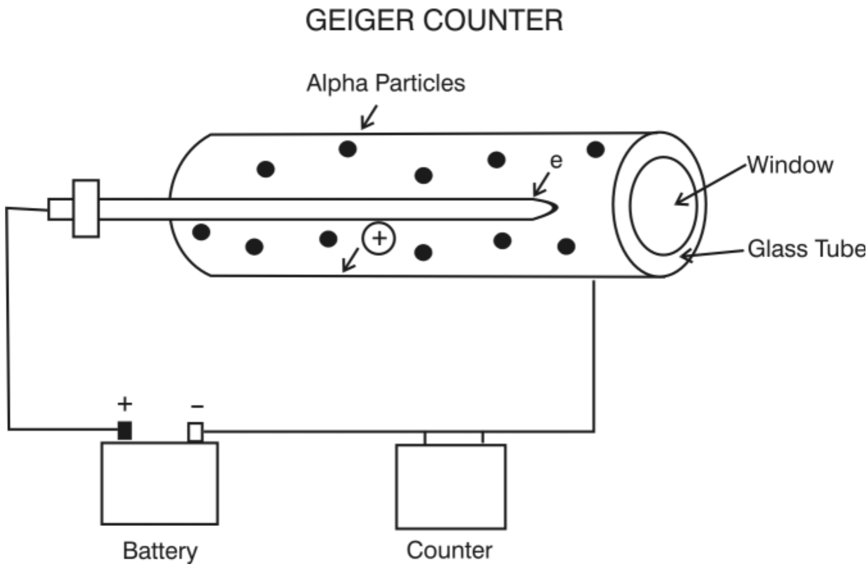


Figure G7. The *Geiger-Müller Tube* contains a high voltage wire that runs down the central axis of a glass tube. It is filled with a gas that becomes ionized, resulting in pulses of electric current that are detected by a sensitive meter and counter that registers continuous readings of the strength of radiation being detected.

A more simple way of stating this law/rule is to say that the short-lived radioactive isotopes emit alpha particles (helium nuclei) more energetically than the longer-lived radioactive isotopes.

Hans Geiger worked with Ernest Rutherford as they performed Rutherford's famous experiment on radioactivity and transmutation in the early 1900s. Geiger's task (*see* Rutherford) was to devise a way to detect and count the number of alpha particles resulting from radiation that caused ionization. To accomplish this task Geiger and Rutherford devised a counter in 1908 that was able to count the number of alpha particles as well as other forms of ionizing radiation. Over the next several years Geiger improved the accuracy and sensitivity of his counter and in 1928, with Walther Müller (1905–1979), a graduate student of his, produced the modern instrument known as the Geiger–Müller counter. This instrument has a glass tube with a wire that carries a high voltage running down the central axis of the tube. It is filled with a gas that becomes ionized when a form of ionizing radiation passes through the tube and ionizes the gas, resulting in

> Hans Geiger's birth name was Johannes Wilhelm Geiger. He attended the University of Munich and the University of Erlangen in Germany where he earned a PhD in 1906 for work with the nature of electrical discharges on various gases. During the years 1907 to 1912 he worked with the famous English physicist, Ernest Rutherford. Rutherford made his famous discovery on the structure of the atom based on work done by Geiger and Ernest Marsden (1889–1970), a physicist from New Zealand, who in 1909 actually set up the experiment that detected the scattering of alpha particles by a sheet of very thin gold leaf. Following his work with Rutherford, Geiger held several administrative positions and by 1925 became professor of physics at Kiel University in Germany.

Margaret Geller's childhood and early education was not typical for a girl raised following the period of World War II. At that time there were not as many women in the fields of mathematics and astronomy as there are today. Currently, there are a higher percentage of women attending college than men. And, the enrollments of women in prestigious universities, such as Massachusetts Institute of Technology, Harvard, Princeton, Cal Tech., and University of California at Berkeley, are now at an all-time high.

As a small child, Margaret was interested in mathematics and science. She attended the University of California at Berkeley and later was awarded a PhD at Princeton. Upon completion of her doctorate, she studied astronomy at Cambridge, England, and in 1980 moved to Harvard where she became a professor of astronomy. Margaret Geller is also on the staff of the Smithsonian Astrophysical Observatory where she continues to be involved with research in astrophysics and cosmological theory with the expectation that new models of the universe will be forthcoming.

a pulse of electric current that is detected by a sensitive meter connected to the glass tube.

See also Rutherford

GELLER'S THEORY OF A NONHOMOGENEOUS UNIVERSE: Astronomy: *Margaret Joan Geller* (1947–), United States.

A map of the redshifts of the light from galaxies indicates a nonuniform distribution of galaxies in specific sections of the observable universe.

By using the Doppler effect, astronomers Margaret Geller and John Huchra (1948–) observed the distribution of over fifteen thousand galaxies while at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts. They recorded the longer light rays toward the red end of the spectrum, indicating that the galaxies are receding. Light from some of the galaxies started its journey to Earth about six hundred and fifty million years ago, and these galaxies are still receding from us, as well as from each other. According to the big bang theory of an ever-expanding universe proposed by Lemaître, and George Gamow, the universe should be rather uniform, or at least galaxies should be randomly distributed throughout all sections of the heavens. When Geller plotted her data for one section of the sky, she discovered very large groups or clusters of galaxies rather than a random or uniform distribution. Some clusters were many hundreds of millions of light-years across in size. She also noted there were a few galaxies between these clusters, but the clusters contained the majority of all visible galaxies. The implication of this information is unclear, as it relates to future cosmological theory. More recently, superclusters composed of clusters of galaxies have been discovered, which seems to support Geller's theory of a nonhomogeneous universe. Geller suggests a revision may be needed for the current big bang model.

See also Doppler; Gamow; Hubble; Lemaître

GELL-MANN'S THEORIES FOR SUBATOMIC PARTICLES: Physics: *Murray Gell-Mann* (1929–), United States. Murray Gell-Mann received the 1969 Nobel Prize for Physics.

Gell-Mann's quark theory: *The heavy particles of atoms (protons and neutrons) are composed of three fundamental entities called quarks.*

Quarks, as proposed by theoretical particle physicists, are considered the most fundamental building blocks of matter yet discovered. String theory proposes a more basic

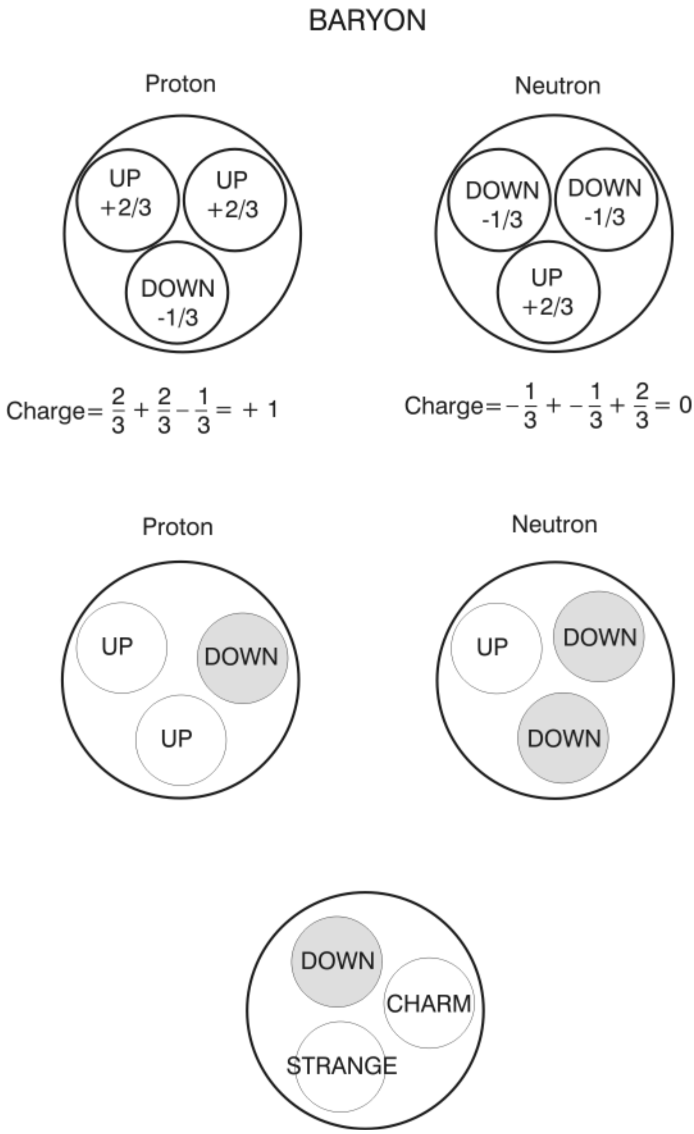


Figure G8. The types of subnuclear particles found in protons and neutrons (baryons).

particle, but it has yet to be discovered, and although there is mathematical justification for the extra dimensions required for the string theory, there is no empirical evidence that they exist. Quarks come in groups of threes (originally named red, blue, and green by Gell-Mann), have a fractional electric charge and have not yet been detected in a free, uncombined state in nature but are being investigated by using a supercollider (RHIC) at Brookhaven National Laboratory on Long Island, New York. By "smashing" nuclei of gold atoms together at 99.9% the speed of light, researchers hope to create some "free" quarks. Being submicroscopic, quarks have never been observed, but they are also considered to be bound up within the interior of the **subatomic particles**. For

FLAVOR AND CHARGE OF QUARKS

Quark Flavor	Symbol	Charge	Relative Mass
Up	u	$\frac{2}{3}$	1
Down	d	$-\frac{1}{3}$	2
Strange	s	$-\frac{1}{3}$	40
Charm	c	$\frac{2}{3}$	300
Bottom (beauty)	b	$-\frac{1}{3}$	940
Top (truth)	t	$\frac{2}{3}$	34,000

Figure G9. The descriptive names given to the flavors and charges of quarks.

instance, the two heavy subatomic particles in the nucleus of atoms belong to a class of particles known as **baryons** (meaning heavy). These two baryons are the positive proton that is composed of two up quarks and one down quark held together by *gluons*, and the neutral neutron which is composed of two down quarks and one up quark (*see* Figure G8).

Gluons and their quarks are responsible for the strong interactions that hold nuclei together. There are three types of quark pairs (for a total of six types of quarks): the *u* quark has a charge of $+2/3$, and the *d* quark and *s* quark have a charge of $-1/3$; thus symmetry is preserved (*see* Figure G9.)

Looking for some way to express the triad nature of these theoretical particles, Murray Gell-Mann borrowed the word "quark" from James Joyce's book *Finnegans Wake* (1939), "Three quarks for Muster Mark!" (This might be interpreted as three quarts of ale for Mister Mark for a job well done.) Gell-Mann liked the sound of this, and it seemed to fit the concept of his triplet of quarks: *u* for up, *d* for down, and *s* for strange, which was intended to explain the organization of the myriad subatomic particles. Since the time that Gell-Mann first advanced his three quarks theory, many other subatomic particles have been proposed. The **hadrons** are a series of heavier quarks, referred to as the *c*-quark (for *charm*), which is many times heavier than, but related to, the moderately heavy *s*-quark (for *strange*). Hadrons are a group of particles such as the baryons and mesons that lead to symmetry. Quarks never exist as individual particles but rather in groups called "hadrons" which, in combinations, are known as "quark confinement." Today the six quarks are named *up, down, charm, strange, top*, and *bottom*. The *u*-up and *d*-down quarks are thought to be just about massless but make up almost 100% of all the matter (protons and neutrons) in the universe whereas the others, produced in particle accelerators, are unstable and have a very short existence.

Gell-Mann's theory of strangeness: *All fundamental particles are characterized by the property of strangeness.*

The concept of strangeness evolved because of the odd or "strange" manner in which some elementary particles strongly interacted. Strangeness is conserved in the strong and electromagnetic interactions of hadrons and the *s*-quark, but not so for weak interactions. If for ordinary particles we assign $S = 0$, then we can allow $S \neq 0$ to represent "strange." Therefore, *S* equals "strangeness." This concept of strangeness led to the development of a new concept for the physical principle of symmetry, used to classify subatomic particles that interact strongly, such as the *c*- and *s*-quarks. The new concept of symmetry, also referred to as the *eight-fold-way*, resulted in the discovery of several new particles, including the omega minus.

See also Feynman; Freidman; Glashow; Nambu

GERHARDT'S TYPE THEORY FOR CLASSIFYING ORGANIC COMPOUNDS: Chemistry: *Charles Frédéric Gerhardt* (1816–1856), France.

Organic chemistry consists of four ''types'' or derivatives related to water, ammonia, hydrogen, or hydrogen chloride.

Gerhardt's type theory had a revolutionary effect on the field of organic chemistry. Previously Jöns Berzelius' proposed a *dualistic system theory* of chemistry that was unsatisfactory in explaining the nature of chemical reactions, whereas, Jean Baptiste Dumas' *substitution theory* was more acceptable, and thus was more-or-less combined by Gerhardt into a *theory of types* for the structure of organic compounds. Gerhardt did much to reform the system of chemical formulation by stressing the distinctions between atoms, molecules, and equivalents into a single type system.

Gerhardt considered that organic chemistry was formulated from four types of inorganic substances: (Type I) H_20 (water); (Type II) NH_3 (ammonia); (Type III) HCL (hydrochloric acid); and (Type IV) H_2 (hydrogen). His theory stated that all *organic* compounds were derived from these four types of *inorganic* substances. He further classified other substances according to these four types as 1) the sulfides, tellurides, oxides, acids, bases, salts, ethers, alcohols, and so forth, belong to Type I, the water types; 2) nitrides, phosphides, arsenides, and other related chemicals belong to the Type II, the ammonia types; 3) the chlorides, bromides,

In 1853 Charles Frédéric Gerhardt, a French chemist, neutralized salicylic acid by buffering it with sodium and acetyl chloride which created acetylsalicylic anhydride, an effective pain reliever now known as aspirin. Up to this time, and as far back as the fifth-century BCE, willow bark was used to relieve pain, fever, and chills. It was later found that when oxidized the extract of the willow bark became salicylic acid. Another extract from meadowsweet flower produced an extract that was just as effective but caused digestive problems. After Gerhardt buffered the extract, he lost interest and had no desire to commercialize the product. Since that time, salicylic acid, better known as aspirin, was marketed by Friedrich Bayer & Co. in Germany along with another pain killer, called heroin, which was much more effective but after some use proved to be addictive. Aspirin was first sold as a powder and was widely used. In 1915 Bayer & Co. produced aspirin in tablet form as it is used today. Several people and companies have claimed to have invented acetylsalicylic acid (aspirin), but Bayer was the company that marketed it most effectively, and Felix Hoffman, a research assistant at the Bayer Co., is generally recognized as its ''official inventor.'' The name ''aspirin'' was patented but the patent has been abused for years, and aspirin is now considered a common, over-the-counter (OTC) drug.

iodides, and other halogens belong to Type III, the hydrochloric acid types; and 4) most metals and metallic hydrides belong to Type IV, the hydrogen types.

For some time organic compounds were referred to using this classification of system of "types." This system was particularly useful when the characteristics of certain organic substances were converted into different, more useful compounds. This was done during the reaction when a specific organic compound had one or more of its hydrogen atoms replaced with an atom different from the hydrogen atom (or a group of different atoms known as a "radical.") By replacing the hydrogen atom(s) a different organic compound was created. One of the great advantages of Gerhardt's scheme was that unknown, and undiscovered chemical compounds could be created, but predicted by using this theory of classification. This system led to a plethora of the many different organic compounds produced today.

GIAUQUE'S THEORY OF ADIABATIC DEMAGNETIZATION: Physics and Chemistry: *William Francis Giauque* (1895–1982), United States. William Giauque received the 1949 Nobel Prize for Chemistry.

> *By cooling an already cold substance in liquid helium within a magnetic field, and then removing the magnetic field (demagnetization), strong entropy occurs, thus greatly lowering the temperature to near absolute zero of the substance being cooled.*

William Francis Giauque in 1927 and Peter Debye in 1926 independently arrived at the theory for **adiabatic** demagnetization as a means for obtaining temperatures that approach a small fraction of absolute zero.

The magnetic field is used to control the entropy of a sample substance consisting of paramagnetic salts that are referred to as the "refrigerant." The magnetic field aligns the **dipoles** of the molecules in the refrigerant while it is kept at a constant temperature with what is called a "heat sink" consisting of liquid helium (a "heat sink" is any substance that absorbs heat and/or shields something from heat). The heat sink removes most of the heat from the "refrigerant" and protects it from absorbing more heat. At this point, the magnetic field is turned off which causes a change in the dipole arrangement of the substance's molecules' positions slowing its molecular motion, thus the temperature of the refrigerant is cooled below that of the liquid helium heat sink with a temperature just 4K, which means it is just four degrees above absolute zero. (Remember, heat is a form of kinetic energy related to the degree of motion of the molecules composing a substance. Reducing the temperature, in essence reduces molecular motion and thus the heat of a substance.) This process increases entropy, whereas the paramagnetic salts' molecules are trapped at a lower energy state (reduced molecular motion) with temperatures as low as 0.0015K, which is just above absolute zero. Zero kelvin is the theoretical temperature point at which all molecular motion ceases.

Since the days of William Giauque's and Peter Debye's experiments, more elaborate low-temperature refrigeration techniques and equipment have been developed. These are referred to as nuclear demagnetized refrigeration (NDR). This method uses adiabatic nuclear demagnetization instead of electric demagnetization to control the molecules' nuclear spin (aligning nuclear dipoles). Temperatures as low as 0.000016 degrees kelvin have been reached as a result of using this system.

William Giauque, in cooperation with Ohio State University chemistry professor Herrick L. Johnston (1898–1965), discovered the presence of the oxygen isotopes O-17 and O-18 and that these two heavier isotopes were mixed with the lighter, more abundant O-16 in Earth's atmosphere. At one time, physicists set the mass of the oxygen-16 isotope at 16.000 as the base for determining the masses of all other elements. After the discovery of oxygen-17 and oxygen-18 in 1929, the new mass figure for oxygen was set at 16.0044. Although this change in the standard unit for atomic mass was small, it caused many problems because, at the time, scientists were using different scales for atomic weights. In 1961 physicists and chemists compromised and set the isotope carbon-12 as having a mass of 12.0000 as the standard. Under this system, oxygen now has an atomic mass of 15.9994. Today, the atomic mass of an element is considered the *average* of the mass numbers of all the isotopes of that particular "natural" element (meaning the isotopes of elements that have been on Earth for eons of time).

Giauque is also well known for his work in the field of chemical thermodynamics. He clarified the influence of atomic and molecular structures on entropy and how this related to the laws of thermodynamics.

See also Carnot; Kelvin; Maxwell

GIBBS' THEORY OF CHEMICAL THERMODYNAMICS: Mathematics and Physics: *Josiah Willard Gibbs* (1839–1903), United States.

> *Mathematics can be applied to determine the interrelationship between heat and chemical reactions, as well as the physical changes of state in the field of thermodynamics.*

Chemical thermodynamics is the interrelationship of heat with chemical reactions (exothermic and endothermic), and with the physical change of state (solid, liquid, or gas) within the parameters of thermodynamics. In essence, this means that mathematical methods can be used to explain the relationships of heat to chemical reactions.

Gibbs was one of only a few famous physical scientists from the United States in the 1700 and 1800s. Others were Benjamin Franklin, Joseph Henry, and Henry Augustus Rowland (1848–1901). However, Gibbs is considered to be the only truly theoretical physicist and chemist in United States at that time. He was also known as a linguist and mathematician. He received the first PhD in engineering awarded by Yale University. Today, the Gibbs Professorship in physical chemistry at Yale is named after him. His work, in essence, established the fields of chemical thermodynamics and statistical mechanics expressed in esoteric mathematical forms. His research papers were difficult to understand, even for other scientists, and in some ways, he was better known and respected by European scientists than those in the United States.

Through writing a series of important papers, Josiah Willard Gibbs established the field of chemical thermodynamics. The paper "On the Equilibrium of Heterogeneous Substances" written in 1876 expressed his famous "Gibbs phase rule" that explained the conditions required for a chemical reaction to take place. Later, he published several important papers including his concept of "Gibbsian ensembles" that explained how a large number of macroscopic entities that have the same heat properties are related statistically.

He developed a concept called "Gibbs free energy" in the field of thermodynamics that is basically a complicated mathematical expression of thermodynamics. He also considered that the energy involved in thermodynamic systems is available to do work. It is expressed in the following formula:

$G = H\text{-}TS$ where in metric units:
G is expressed in the unit known as joules (Gibbs energy)
H is expressed in *joules* for *entropy*
T is the temperature given in *kelvin*
S is the entropy expressed in *joules per kelvin*.

This equation basically states that every chemical and physical system seeks to achieve a minimum of free energy. It is important for determining the thermodynamic functions of such systems to establish the equilibrium constants. This applies for any reversible chemical reaction, for example, $N_2 + 3H_2 \leftrightarrow 2NH_3$. (The $\leftrightarrow$ double arrow indicates a forward and reverse chemical reaction.) Another example that uses the *Gibbs free energy* formula is measuring the output voltage from an electrochemical cell.

See also Carnot; Giauque; Maxwell

GILBERT'S THEORY FOR DNA SEQUENCING: Biology: *Walter Gilbert* (1932–), United States. Walter Gilbert shared the 1980 Nobel Prize for Chemistry with Frederick Sanger and Paul Berg.

Chemicals can be used to modify DNA by sequencing base pairs of DNA in either single strands or double strands of DNA that then can be used to study the interactions of proteins with the DNA.

Walter Gilbert was educated as a physicist at Harvard University and at Cambridge University in England where he received his degree in 1957. After studying the fields of chemistry and physics, he developed an interest in biochemistry, primarily after meeting with and learning of the research and experiments that James Watson (of Crick and Watson fame) was conducting. Consequently he switched to the field of molecular biology in 1960 and in 1968 became a Harvard professor of microbiology and later became department chairman. Gilbert worked in the United States with Allan M. Maxam, a graduate student, while Frederic Sanger worked independently in England to make use of new techniques, such as electrophoresis for the analysis of results achieved by their method of multiplying, dividing, and fragmenting a large section of DNA strands. They used chemicals to break large strands of DNA into smaller fragments along the bases of (A) adenine; (G) guanine, (C) cytosine, and (T) thymine. The main difference between Gilbert's method of sequencing DNA and Sanger's was that Sanger's method only worked with single strands of DNA, whereas Gilbert's methods were effective for either single or double strands of DNA (*see* Figure C5 under Crick for a diagram of the DNA molecule.) The techniques for sequencing DNA devised by Gilbert can be used to read up to thirty thousand base pairs.

Over the past fifty years a number of methods for sequencing DNA have been developed. In addition to "chemical sequencing," Sanger developed a "chain termination method." Another procedure is the "dye terminator sequencing." Just as important as the techniques for sequencing DNA is the improvement for the preparations of the samples and developing automated procedures for the sequencing operations. Currently, the number of sequences of short lengths of DNA is limited due to the power of resolution of the systems used. The magnitude of the problem is realized because even simple single-cell bacterium can have a genome of about a million base pairs while the human genome has more than three billion base pairs in their DNA molecules. Recently to overcome these problems, several techniques were developed to get a "reasonable" reading of the human DNA genome. One technique is to clone a sample and "grow" copies of the desired DNA at a rate of thousands of pairs at the same time. Another method is called "shotgun sequencing" that uses small samples of DNA and then assembles them into a connected sequence. No doubt, in the future, improved faster methods will be developed to determine the complete genome of any plant or animal, including a more detailed map of the human genome.

See also Crick; Sanger; Sharp; Watson (James)

GILBERT'S THEORY OF MAGNETISM: Physics: *William Gilbert* (1544–1603), England.

Gilbert's theory for electric and magnetic forces: *The amber effect (static electricity), which can attract small particles when certain materials are rubbed with certain types of cloth, such as silk, is not the same phenomenon as natural magnetism, which exists in lodestones (magnetic iron ore).*

The phenomenon of rubbing amber with cloth to cause the amber to attract bits of straw and other small particles was known since the days of the Greek philosophers. They related it to some magic or spirit, not to static electricity. William Gilbert experimented with amber to produce static electricity and lodestones to magnetize iron bars. He was the first to distinguish these two forces of attraction and the first to use the terms "electric attraction" and "magnetic attraction" to make this distinction.

Gilbert's theory for the rotation of Earth: *Because a magnetized needle will swing horizontally as it points to the poles of Earth and also dip down toward the vertical, Earth must be a giant spinning lodestone.*

William Gilbert's experiments formed his magnetic philosophy, eliminating much of the superstition and false information about magnetism existing at that time. He constructed a globe from a large lodestone to demonstrate how a compass needle behaves on the lodestone and then related this to Earth. Because of the action of a compass needle, he assumed that the "soul" of Earth was also a spherical lodestone with a north and south pole. In addition, he demonstrated that the compass needle would dip down at different angles as related to the different latitudes, and the needle would point straight down at the north pole of his lodestone globe. Thus, it would do the same for the North Pole of Earth. Sailors had already observed this "magnetic dip" phenomenon, but Gilbert was the first to relate Earth's magnetism to latitudes. Gilbert concluded that Earth acts like a large, spherical bar magnet, which is spinning on its axis once every twenty-four hours. However, he continued to believe Earth was the center of the universe. His theory was the first reasonable explanation for a rotating Earth, but Gilbert did not go as far as Copernicus, who claimed Earth moved through the heavens around the sun. Up to this time, scientists believed Earth was stationary, and the canopy of stars was in motion. Historically, the magnetic compass was a reliable instrument that aided in navigation. Gilbert's magnetic philosophy, which included the belief that Earth's magnetic influence affected everything in the solar system, led to the modern concept of gravity. One gilbert (Gb), a unit of electromotive force, named for him, is equal to the magnetomotive force of a closed loop of wire with one turn in which the flowing current is 1 ampere. In the CGS (centimeters, grams, seconds) system, 1 Gb is equal to $10/4\pi$ ampere turns.

See also Ampère; Coulomb; Faraday; Maxwell; Oersted

GLASER'S CONCEPT OF A BUBBLE CHAMBER FOR DETECTING SUBNUCLEAR PARTICLES: Physics: *Donald Arthur Glaser* (1926–), United States.

High-energy ionized particles that cannot be detected in a Wilson cloud chamber can be detected by leaving a trail in a depressurized fluid bubble chamber, and the trail representing characteristics of the particles can be captured by high-speed photography.

Donald Glaser received his PhD degree in physics in 1950 from the California Institute of Technology. He taught and did research in various areas at the University of Michigan, and was promoted to the rank of full professor in 1957. In 1959 he moved to the Berkeley campus of the University of California where his interests spread to the

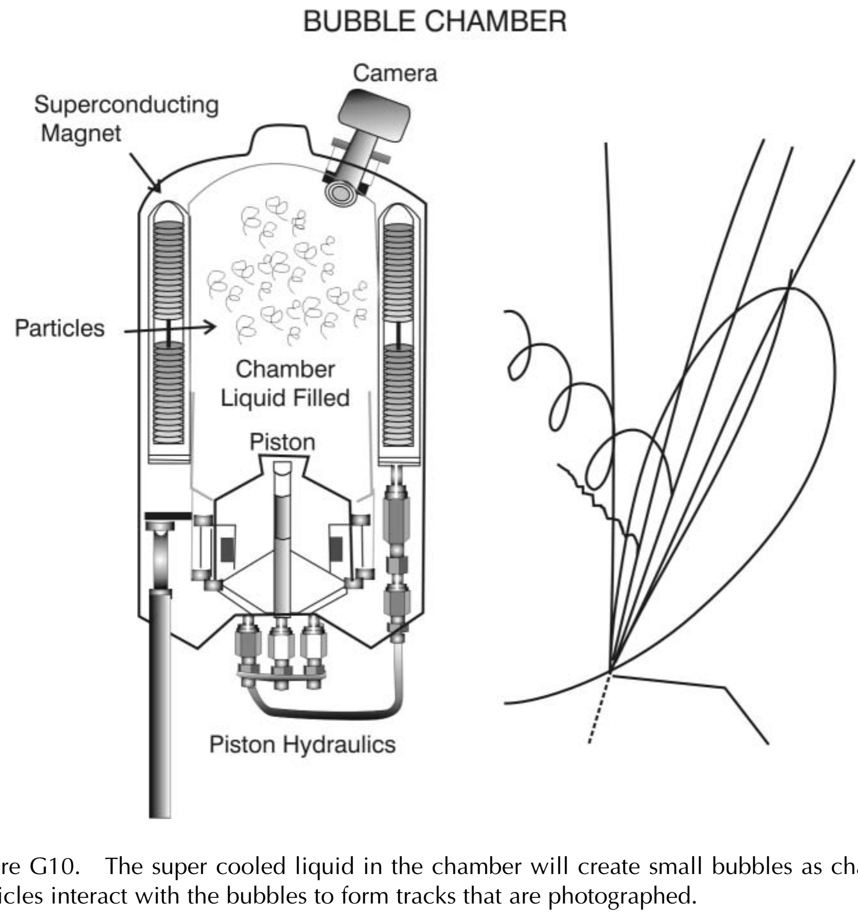


Figure G10. The super cooled liquid in the chamber will create small bubbles as charged particles interact with the bubbles to form tracks that are photographed.

area of biology as well as physics. His early work with the Wilson cloud chamber that was used to detect cosmic rays led him to realize that the cloud chamber was an inadequate instrument to detect subnuclear ionized high-energy particles. While at the University of Michigan, he became aware that high-energy particles passing through a superheated fluid would produce small bubbles along a specific trajectory. His design for the bubble chamber consisted of a large cylinder filled with a liquid that was heated almost to its boiling point. The cylinder is surrounded by a magnetic field with a high-speed camera positioned at the top and focused down into the chamber. A piston that can be moved up and down is located at the bottom of the cylinder. As the piston is rapidly lowered, the pressure in the cylinder's chamber is reduced and the liquid becomes supercooled. This supercooled liquid will create a series of tiny bubbles as the charged particle interacts with an atom of the liquid. At that moment, the camera captures the image of the bubble track that is then used to determine the decay modes, lifetime, spin, cross section, and other characteristics of the subnuclear particle (*see* Figure G10 for an artist's depiction of a bubble chamber and particle tracks).

Today's bubble chambers are much larger than the original one invented by Glaser in 1952. They use liquid hydrogen or liquid helium for the fluid. Another type of bubble chamber that requires heavy liquids to slow down the particles uses organic compounds. But the principle of the cloud chamber and bubble chamber are basically the same. The use of these unique research instruments has resulted in the identification of many new types of elementary particles.

Donald Glaser has received many honors for his contributions in the fields of physics and biology. More recently, Glaser has been interested in applying physics to problems related to molecular biology. His current position is professor of physics and neurobiology in the Graduate School at Berkeley.

See also Compton; Millikan; Wilson (Charles)

GLASHOW'S UNIFYING THEORY OF THE WEAK FORCES: Physics: *Sheldon Lee Glashow* (1932–), United States. Sheldon Glashow shared the 1979 Nobel Prize of for Physics with Steven Weinberg and Abdus Salam.

> *The unification of the electromagnetic interactions with the interaction of leptons (electrons and neutrinos) can be extended to include baryons (a heavy particle) and mesons (elementary particles with a baryon number of zero) by establishing a new, fourth "charm" quark to add to Murray Gell-Mann's three-quark theory.*

Sheldon Glashow was born and raised in Manhattan. He attended the Bronx High School of Science, along with another future famous scientist Steven Weinberg. He attended Cornell University and received his PhD degree from Harvard University in 1959. He was granted a National Science Foundation (NSF) fellowship to Russia but never received the required visa from the Soviet government. Rather he spent his fellowship at the Niels Bohr Institute in Copenhagen where he did his original work on the structure of the electroweak theory. Later back in the United States, Glashow and two other scientists predicted that "charm" would be discovered, as well as realizing that many of the theories related to subatomic particles, forces, and fields were more-or-less merging into a future single theory of all universal physical principles. Glashow's

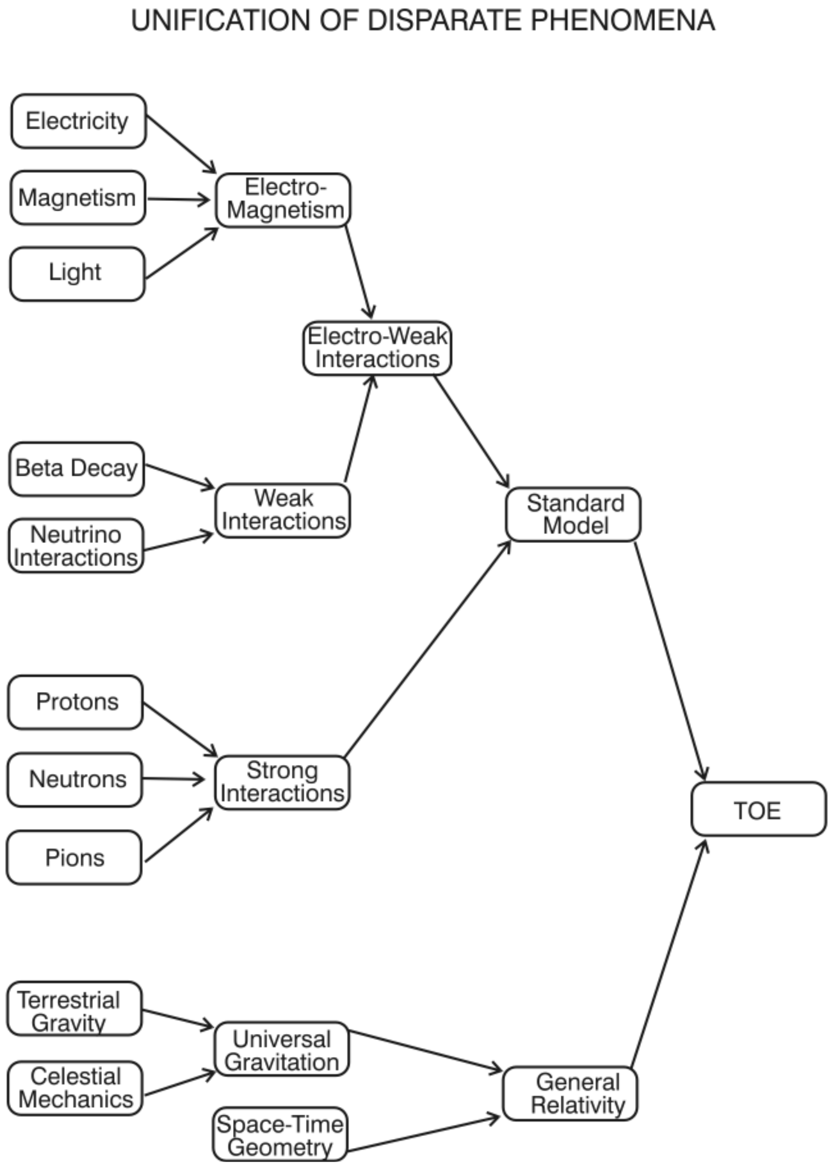


Figure G11. The standard model for physics particles. If a way can be found to combine this theory with the theories of universal gravity and the quantum field theory, it could result in a ''Theory of Everything'' (TOE) viz., a theory for all energy and matter.

research had gone a long way towards advancing this concept of a "theory of everything" (TOE) by predicting the "charm particle" as another type of quark (*see* Gell-Mann). Possibly more important was his contribution to establishing the unification of the "weak" and "electromagnetic" forces as "electroweak interactions" that are part of the standard model for particle physics (*see* Figure G11).

If the standard model for particle physics can be successfully combined with the concepts of universal gravity, relativity, and quantum field theory a grand unification theory (GUT) or theory of everything (TOE) may become a reality.

There are four basic or fundamental forces (sometimes referred to as fields) that naturally exist in the universe. Following is a brief description of these forces listed from the weakest to the strongest.

1. *Gravitation force*: Gravity exists throughout the universe and is experienced everywhere where there is matter (there is no negative gravity). Gravity acts on all particles no matter where located in the universe. Scientists have theorized that the force of gravity itself is composed of particles called "gravitons."
2. The *electromagnetic force* (field): This force acts on all electrically charged particles. The "particle" of electromagnetic force is called the "photon," which has particle and wave-like characteristics.
3. *Weak nuclear force:* This force causes radioactivity to act on electrons, neutrinos, and quarks. The particle's repulsive nature of the weak nuclear force is known as the "W boson."
4. *Strong nuclear force:* This force is responsible for the quarks that form neutron and protons in atoms' nuclei. Quarks also are responsible for "holding" together the neutrons and protons of the atoms' nuclei. The particle related to this force is called the "gluon."

GODEL'S INCOMPLETENESS THEOREM: Mathematics: *Kurt Godel* (1906–1978), United States.

> *Using axioms that are true within that system cannot prove the consistency for any formal system, including formal arithmetic and logic systems. A stronger system is required that has an assumed consistency.*

The explanation of Kurt Godel's incompleteness theorem is the opposite of a complete theorem, which involves a system where all logical statements made by a formal system can be proved by **axioms** of that very system. Godel claimed no formal system could meet that criterion. The incompleteness theorem may also be stated for mathematics as: *No finite set of axioms is adequate to form the basis for all true statements concerning integers, and there will always be statements about integers that cannot be proved to be either true or false.* The Godel incompleteness theorem also holds for nonmathematically based systems of logic, where a proposition can neither be proved nor disproved based on axioms of that particular system. Godel's incompleteness theorem disturbs many scientists because a noncontradictory system of mathematics may never be constructed, and the means to understand the physical nature of the universe fully may never be found. This theory has implications for mathematics in the sense that, if Godel's theory holds up, there are fundamental limits within the field of mathematics, as well as limitations on the acquisition of scientific knowledge about the universe.

Godel worked closely with Albert Einstein on the mathematical and practical aspects of the general relativity theory. He was particularly interested in concepts of time and at one time proposed that, theoretically, it was possible to travel back in time. Toward the end of his life he was plagued by mental and physical problems. Godel admitted that he could neither keep up with nor understand the newer theories and works of younger mathematicians. As his illness progressed, he believed he was being poisoned. Thus, he stopped eating and starved himself to death.

GOLD'S COSMOLOGICAL THEORIES: Astronomy: *Thomas Gold* (1920–2004), United States.

Gold's theory for the nature of the universe: *The universe exists in a steady state. It is unchanging in space and time, with no beginning or ending.*

Thomas Gold and some other astronomers rejected the big bang concept for the origin of an ever-expanding universe. In 1948 Gold referred to his theory as the *perfect cosmological principle*: a universe with no beginning and no ending, and thus the steady-state universe. In addition, his universe appears the same regardless of where it may be viewed, which was just the opposite of Margaret Geller's concept of a nonhomogeneous universe (*see* Geller). In other words, Gold's theoretical universe has a density that is not only constant, but all matter and energy will always be maintained in the same relative proportions. Because this theory conflicts with the laws for the conservation of matter and energy (laws of thermodynamics), the proponents of the steady-state universe needed to produce an idea for the continuous creation of matter and contended that this is just what occurs. Gold postulated that a continuous production of one hydrogen atom per cubic kilometer of space occurs every ten years. Although this amount of "new" hydrogen is undetectable and the vacuum of space is better than any vacuum that can be produced mechanically on Earth, it is an adequate "regeneration" of hydrogen to confirm the laws of conservation and maintain a steady-state universe. Currently, it is estimated that "empty" space contains one proton (hydrogen nucleus) per cubic centimeter (*see also* Geller).

Gold's theory for neutron stars: *The detectable high-frequency, periodic radio signals originating in pulsars are caused by rapidly rotating neutron stars.*

In 1968 British astronomers Jocelyn Bell Burnell (1943–) and Antony Hewish discovered that very short bursts of radio waves were being emitted every second from a new type of star they referred to as *pulsars* because the signals seemed to "pulse" on a very regular basis. Gold contended these signals originated from rapidly rotating neutron stars, which are extremely dense, spinning bodies that underwent collapse on a gradated basis. Neutron stars, through nuclear fusion, have exhausted their nuclear fuel. The result is that gravity becomes so extreme that the stars collapse into themselves, to the point where their protons and electrons combine to form neutrons. At the end of their "lives", these neutron stars collapse into a *black hole*. Because these stars are very small and very dense, their rotation period can be short enough to produce the detected high-energy radio signals. Gold's theory was substantiated when a new pulsar neutron star with a more rapid rotation was located in the Crab Nebula, even though this pulsar is slowing down about 3.5 seconds every trillion years.

Gold's theory of life on Earth and Mars: *Conditions on and below the surfaces of Mars and Earth are very similar and both may support life.*

Thomas Gold made many comparisons between the structure and conditions existing on Mars and Earth—for example:

- Several **meteorites** found in Antarctica appear to have come from Mars. Some contain several rare noble gases (e.g., neon and xenon), as well as nitrogen isotopes, unoxidized carbon, and petroleum-like hydrocarbon molecules.
- Heat on Mars and Earth increases with depth, and both must have water at some depth below surface levels. This deep liquid water came to the surface on Earth, but not on Mars, where the subsurface temperature keeps the water frozen.

- Although the surface chemicals on Mars and Earth are different, their subsurface chemistry seems similar. Both planets exhibit leftover debris, including meteorites, from their formation billions of years ago.
- Stable hydrocarbon molecules under great pressure are found at great depths on most planets. Earth's carbon-containing liquid and gas petroleum help maintain the carbon cycle by seeping to the surface where carbon dioxide from hydrocarbons is transported to the atmospheric-ocean-rock environments and then recycled by green plants. A similar process occurs for many planets but without the green plants, as we know them. All the major outer planets (Jupiter, Saturn, Uranus, and Neptune) have enormous amounts of hydrocarbons, mainly methane and ethane, plus ammonia in their atmospheres that are recycled as *petroleum rain*. Different forms of hydrocarbons have also been detected on the surfaces of asteroids.
- Evidence suggests that living organisms did not form these deep hydrocarbons. Rather, these primordial hydrocarbons were mixed with biological molecules and are a prerequisite for life. A dilemma exists because primitive microbes must in some way oxidize the hydrocarbon molecules to obtain energy, but the deep interior of planets does not contain such "free" oxygen. A possible means of oxidizing hydrocarbons would be for the deep microorganisms to use sulfur and iron sulfate compounds to oxidize and dine on the hydrocarbons. Organisms that thrive on sulfur have been found at the site of sulfur "vents" discovered at great depths on Earth's ocean floor.
- Life on Earth most likely started internally, not from transport of "organic seeds" to the surface from space or by other surface phenomenon. Therefore, life may be found at a primitive stage below the surface of Mars and some other planets.

In conclusion, without photosynthesis as a source of energy it is very unlikely that Mars has any surface life. But there is a good possibility that at some depth, there is chemically fed life. Physical conditions, such as temperature, radiation, lack of stable liquids, and so forth make surface life less likely than subsurface life on Mars.

See also Gamow, Guth; Lemaître

GOLDSTEIN'S THEORY FOR THE METABOLISM OF CHOLESTEROL, FATS, AND LIPIDS: Biology and Medicine: *Joseph Leonard Goldstein* (1940–), United States. Joseph Goldstein shared the 1985 Nobel Prize in Physiology or Medicine with Michael S. Brown.

> *Cholesterol is found in two main sources: the liver, and in foods. As particles, cholesterol is carried by blood and lymphatic fluid; thus they are vital products of metabolism of human body cells.*

Joseph Goldstein received his MD degree in 1966 from the University of Texas Southwestern Medical School. He did his internship at the Massachusetts General Hospital in Boston where he met his friend and long-time collaborator, the geneticist, Michael S. Brown (1941–). They shared an interest in genetics related to biochemistry, and in particular the study of cholesterol and other lipoproteins.

Cholesterol is formed from two different sources, that is, within the liver and from the fat in food we eat. Cholesterol is transported from the liver by the blood as spherical particles called lipoproteins that are a combination of fat and proteins. There are two types of lipoproteins: LDL (low density lipoproteins), and HDL (high density lipoproteins). The LDL particles are transported in the blood and are considered the "bad" cholesterol because an excess of it can clog the walls of arteries and restrict the flow of blood to the heart, thus increasing the risk of a heart attack or stroke. A healthy person has approximately 2 grams of cholesterol per liter of blood in their system. A person with 10 or more grams of LDL per liter of blood suffers from the metabolic disease called *familial hypercholesterolemia* (FH).

It should be mentioned that cholesterol is a very important chemical required for the proper metabolism of food and should not be eliminated completely from one's diet. It has two main functions in the body. First, it is a constituent of normal cell wall membranes, and two, it is converted to important steroids, hormones, and, bile acid secretions. About 90% of all cholesterol found in the body is incorporated in cell membranes. The deposit of cholesterol particles on the interior walls of arteries is a slow process, taking many years to accumulate enough particles to block the flow of blood. The rate of accumulation may be a factor of genetics (e.g., your parents may have had high cholesterol or died young of a heart attack or stroke). It can also be the result of a long-term diet of foods containing saturated fat (trans fats) along with, smoking, stress, and genetic factors.

Goldstein and Brown conducted extensive research on the nature of cholesterol and its effects on the human body as well as how to reduce the risks associated with familial hypercholesterolemia.

GOULD'S HYPOTHESIS OF "PUNCTUATED EQUILIBRIUM": Biology: *Stephen Jay Gould* (1941–2002), United States.

> *The evolution of a species is a series of episodic changes within relatively isolated populations.*

In 1972 Stephen Jay Gould and Niles Eldredge arrived at their theory of catastrophic evolution they called "punctuated equilibrium" by examining fossil records. They disagreed with Darwin's concept of a slow but continuous organic evolution involving natural selection, which is a ladder-like, smooth progression of changes from one species to variations of species. Gould and Eldredge detected many gaps in the fossil records, which they claimed disputed this smooth progression. Gould believed such a smooth transition was very rare in nature due to a continuous "pruning" of the branching tree of evolution, which results in the extinction of species. He admitted slower transitional evolution might exist for larger populations or groups of species, but not necessarily for individual species. On the other hand, even though patterns found in fossil records indicate that many species are stable, there is evidence that catastrophic ecological events resulted in the abrupt appearance of new species. These new species then adapted to their new environmental conditions. One problem with the Gould–Eldredge punctuated equilibria theory is that fossils by their nature are never complete, and therefore recognizing species from their fossil remains can only be speculative. One commonly accepted example of the catastrophic theory is the extinction of the dinosaurs approximately sixty-five million years ago, about the same time that a massive asteroid struck Earth. It is assumed this collision created a world-covering cloud of dust and smoke that blocked out the sun for several years, resulting in the elimination of plant life and great numbers of animal life as well, including dinosaurs. Obviously, some plant and animal life survived—most likely simple plant life and small mammals and some sea life.

In the 1970s and 1980s Stephen Jay Gould reexplored the concept of recapitulation that had been out of favor with biologists for many years. It is based on the idea that for a variety of animals, the maturation of embryos in the early fetal stages advance through similar stages of basic structural development. At certain stages of development, the embryos of fish, reptiles, birds, mammals, and humans appear very similar in structure. In other words, very early growth for animals represents a recapitulation of eons of evolutionary development from one species to another. Another way to say this is that *ontogeny* (individual development) follows *phylogeny* (evolutionary history).

See also Eldredge; Haeckel

GRAHAM'S LAWS OF DIFFUSION AND EFFUSION: Chemistry: *Thomas Graham* (1805–1869), Scotland.

> *The identity of a gas is based on its physical properties that affect the gas's rate of diffusion and/or effusion.*

Diffusion may be thought of as an increase in the degree of disorder (entropy) that causes a dispersing of one substance throughout a different substance. The force that causes this dispersion is the kinetic energy of the particles in the substance. The molecules in liquid and gaseous substances are much further apart than the particles of solids. For example, if a drop or two of colored dye is placed into a glass of clear water and is not disturbed, in time the dye will be dispersed evenly through the water molecules. The rate of diffusion is much more rapid in gases and liquids than in solids. Even so, if a smooth bar of gold is placed onto a smooth bar of lead and their surfaces are in tight contact, over time there will be some atoms of gold diffused into the surface of the lead. Because molecules are much farther apart in gases than solids, light can pass through the gas without much interference and gases are thus mostly transparent. At the same time, light passing through a clear liquid (with molecules closer together than gases) is more easily deflected than through a gas. Most people have experienced the sensation of knowing when a person who is wearing too much perfume or cologne walks passed them. The reason: molecules of the perfume or cologne are diffused into the moving air as they walk by.

Graham concluded from his investigations of the relationship between the rate of diffusion of a gas and its molecular mass that the rate of diffusion can be expressed either by knowing the gas's density or its molecular mass. Graham's *law of diffusion* states that the rate at which different types of gases diffuse is proportional to the square root of their densities, as expressed by the following equation:

$$\text{Rate of Diffusion} \propto 1/\sqrt{\text{density}}$$

Or, because the same volume of different gases (at the same temperatures) have the same number of particles (*see* Avogadro's Hypothesis), the rate of diffusion can be expressed as proportional to the molecular mass (MM) of the gas, as expressed in the following equation:

During his research on the rate of diffusion Graham observed that some substances pass through a membrane slower than others. He also observed that organic substances (blood, starch, sugar, etc.) diffused more slowly through a porous membrane than did some inorganic chemicals, such as salts (potassium and sodium chloride). He called the substances that passed more rapidly through the membranes *crystalloids* and the slower ones *colloids. Colloid* means ''glue'' in Greek. Since the time of the simple explanation for a colloid in Graham's day, colloidal chemistry has become an advanced science with techniques and procedures used in a great variety of industries, including ceramics, paints, agriculture, cleaning agents, soil treatments, and food preparations. One of the most important uses of Graham's discoveries is in the medical field that developed a ''dialysis apparatus'' used to assist patients who are experiencing some form of renal failure or kidney disease. Small and large particles of undesirable solutes are removed from the blood and are cleansed of impurities. Thomas Graham is recognized as the founder of the expanding discipline of colloidal chemistry.

$$\text{Rate of Diffusion} \propto 1/\sqrt{MM}$$

Graham also studied *effusion* that can be described as the movement (or escape) of the molecules of a particular gas through an opening that is small compared to the average distance the gases' molecules travel between collisions. The equation for the rate of effusion is, in essence, a combination of the above two equations for diffusion.

An interesting application of Graham's laws for the rates of diffusion and molecular mass was the system developed early in World War II to separate the lighter Uranium-235 which is the fissionable isotope from the heavier Uranium-238. A long diffusion chamber over several hundred yards in length was used to separate U-235 as a gaseous version of uranium hexafluoride (UF-6). The concept was that the lighter UF-6 that contained the isotope U-235 would diffuse to the end of the long tunnel faster than the heavy U-238. By using a long tunnel (chamber) the gas collected was enough of the fissionable U-235 to complete the research that led to the atomic bomb.

See also Avogadro; Ideal Gas Law

Much of Guth's inflation theory and ideas that are additions to the big bang theory have recently been confirmed. In 2001 the ''Wilkinson Microwave Anisotropy Probe'' (WMAP) satellite was placed in orbit by a Delta II rocket from Cape Canaveral, Florida. Three years worth of data from WMAP was provided to the public on March 17, 2006. The data includes temperature readings from two points in the sky at the same time, readings of cosmic background radiation, polarization readings, and other important data. As WMAP scans the heavens, it covers about 30% of the sky each day. The data gathered by this probe and other instruments strengthen Guth's theory for the inflationary universe. Note: for those interested NASA has a website where pictures of the ''baby universe'' can be accessed. It is: http://www.gsfc.nasa.gov/topstory/2003/0206mapresults.

GUTH'S THEORY OF AN INFLATIONARY UNIVERSE:

Astronomy (Cosmology): *Alan Harvey Guth* (1947–), United States.

> *The ''newborne'' universe at the instant of the big bang passed through a phase of exponential expansion. The negative pressure of the vacuum of space drove this inflation.*

In 1948 the big bang theory for the origin of the universe proposed by George Gamow and others explained a great deal about the universe as it is today, including background microwave radiation and an ever-expanding universe. But this theory did not explain all observable events. For one, why was the present universe so uniform and similar in all directions of space, while on such a large scale it is more likely to exhibit some major irregularities? To overcome this and other problems perceived with the big bang, Guth first proposed some refinements to the theory in 1980. His inflation theory stated that the new universe underwent an exponential expansion of 10^{30} in the size of its radius within the first microsecond (10^{-43} to 10^{-35} seconds). This first instant of beginning is sometimes referred to as the start of the period of grand unification theory (GUT) where all four physical forces were united into one force. Guth also suggested that the GUT theory provides evidence that it is possible that the universe started from nothing. In other words, there was nothing before the big bang. Scientists today are looking for a similar simple GUT theory that is sometimes called the theory of everything (TOE). This microsecond is also the beginning of the period of the second law of thermodynamics where everything started to become more disorganized and the cooling of the universe began (and continues to cool). This is explained by the laws of thermodynamics.

H

HABER'S THEORIES: Chemistry: *Fritz Haber* (1868–1934), Germany. Fritz Haber was awarded the 1918 Nobel Prize for Chemistry.

The Haber process: *By using high temperatures and a metallic catalyst, atmospheric nitrogen can be chemically combined with hydrogen to form synthesized ammonia* ($N_2 + 3H_2 \leftrightarrow 2NH_3$).

During World War I Germany was cut off from its supply of nitrate salts from Chile, an important source of the chemical used for fertilizers and explosives. Fritz Haber developed the process of using "free" nitrogen from the atmosphere and converting it into "fixed' nitrogen. This synthesis, under normal conditions, produced very limited amounts of useful ammonia. To increase the yield to industrial proportions, in the early 1900s Haber ran hot steam over hot **coke** at 250°C under high pressure of 250 atmospheres (one atmosphere is normal air pressure) while using a catalyst to increase the rate of the reaction, thus producing more ammonia than would be possible during the normal chemical reaction. This is known as the Haber water gas process, where the nitrogen of the air and the hydrogen from the steam are "fixed" as ammonia. Haber was awarded the 1918 Nobel Prize in Chemistry for this achievement. The Haber process was adapted as an industrial process by Carl Bosch in 1913. Bosch's industrial processes resulted in significant amounts of ammonia that could be used for commercial purposes. Ammonia, in its various forms, is one of the major industrial chemicals produced worldwide. Most living plants, with the exception of legumes, such as beans, cannot take in free nitrogen from the atmosphere, but must rely on nitrogen that is found in soil. Without the Haber/Bosch process for the industrial production of fertilizer, the agricultural producers worldwide would be incapable of producing an adequate food supply for an ever-increasing population. In addition to its use in the manufacture of fertilizers, ammonia is used as a refrigerant, and also in the manufacture of synthetic fabrics, in photography, and in the steel and petroleum industries. Regrettably, a form of ammonia fertilizer, when mixed with petroleum, has become a cheap, but effective, type of explosive for a variety of terrorists.

Haber's theory for extracting gold from the oceans: *Gold can be removed from seawater through the use of high pressures and temperatures and proper electrochemical catalysts.*

During World War II Haber assisted the German government in the development of poison gases. After the war, he tried to help Germany pay off its war debts by extracting gold from seawater. In addition to using very high pressures and temperatures with catalysts to increase the speed of extraction of the gold, Haber used an electrochemical reaction to extract the large amount of gold present in seawater—without much economic success. An estimated eight thousand million tons of gold is dissolved in all the oceans' waters. However, to date, no economical process has been devised that would extract a significant amount of gold from seawater. Although his efforts were unsuccessful, Haber's techniques did lead to the current process of extracting bromine from seawater.

HADAMARD'S THEORY OF PRIME NUMBERS: Mathematics: *Jacques Salomon Hadamard* (1865–1963). France.

> *Prime numbers between 1 and n are distributed in an orderly fashion when considered in the formula:* $\pi(n) = n/\log_e n$, *which only works when n approaches infinity.*

In the above formula πn represents the number of the primes between 1 and n (it does not work for small numbers). Although others developed this theorem, Hadamard proved it in 1896.

Although Hadamard is best known for his proof of the prime number, he was interested in a number of other areas of mathematics. Educated at the Ecole Normale Superieure in Paris, he taught in several French universities before accepting the chair of mathematics at the College of France, also in Paris, where he remained until his death. He published over three hundred papers during his career, including one in which he defined a singularity as a point at which the function is no longer regular but was rather a set of singular points that will accommodate continuous functions. In modern mathematics it is referred to as "lacunary space." Hadamard's lacunary space exists as a set of singular points similar to a continuity of a function. The study of this concept by mathematicians, physicists, and cosmologists continues today. Hadamard also advanced the concept of solutions for differential equations. An example is his "well-poised problem" as a problem whose solution exists for a given set of data, but the solution also depends on the continuous use of the given data. In

> In his book *Psychology of Invention in the Mathematical Field* Hadamard investigated how scientists, particularly mathematicians and physicists, did their thinking. He surveyed about one hundred leading scientists of his day and asked how they accomplished the mental aspects of their work. Hadamard used introspection (a means of contemplation of one's own thoughts) to describe his mathematical thought processes and was interested in how others did their work. Some responded that they saw their mathematical concepts in color. Einstein is well known for his "thought" experiments and said he felt sensations in his forearms as he contemplated his ideas. Nikola Tesla was able to formulate his theories in his mind as "models" related to potential inventions based on his theories. He could then, without physically diagramming the models, instruct his workers how to construct working models of his ideas. Others described similar ways of forming mental images that did not use language or cognition to describe their thoughts.

1896 Hadamard proved the prime number theorem that was proposed by Gauss and Riemann, and which has proved to be the most important discovery in number theory.

A prime number is any positive integer (number) that has no divisors except itself and the integer 1. A prime number has just two factors. Therefore, 1 cannot be a prime number. If a number has more than two factors, it is called a composite number. Some examples of prime numbers are: 2, 3, 5, 7, 11, 13, 17, 19, 23, 29, and so on.

See also Gauss; Riemann

HADLEY'S HYPOTHESIS FOR THE CAUSE OF THE TRADE WINDS: Meteorology: *George Hadley* (1685–1768) England.

> *Earth rotating on its axis causes vertical rising hot air from the tropical circulation cell at the equator to form the trade winds that blow westward near the equator and eastward at more northern latitudes.*

Even before the time of Christopher Columbus, sailors knew that when sailing west toward the islands off the coast of Africa they must go south to pick up the westerly winds. They also knew that if they wanted to return to northern Europe and England, they needed to go farther north to pick up the easterly winds. George Hadley attended Oxford University and upon graduation became a barrister. He was more interested in physics than law and became an amateur meteorologist who directed the meteorological research observatory for the Royal Society. He was intrigued with the movements of cold air (that is denser and thus heavier than warm air) that replaced less dense hot

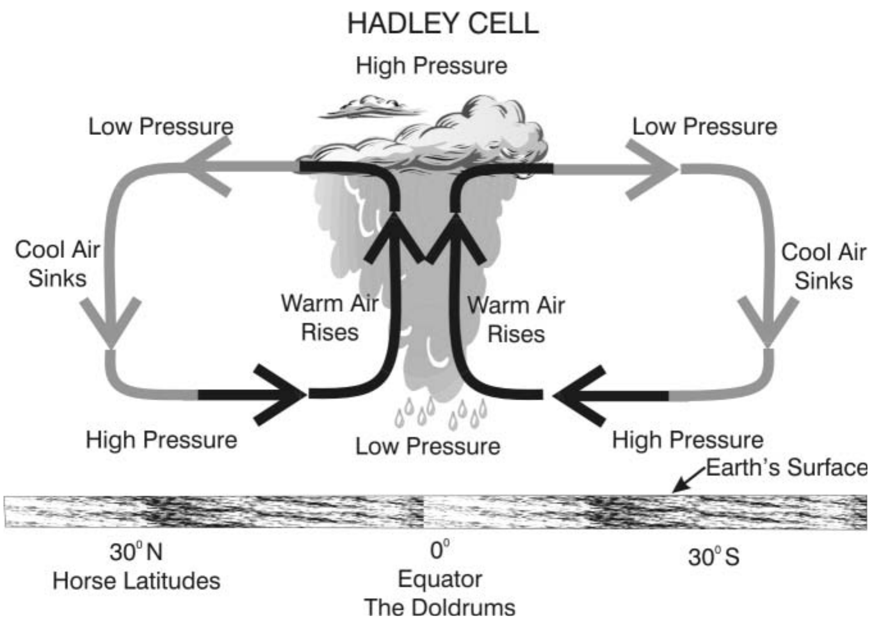


Figure H1. The Hadley cell's circulation is based on the physical principle that warm air is less dense, thus it will rise until it becomes cooler and more dense and therefore will sink toward the surface of the Earth.

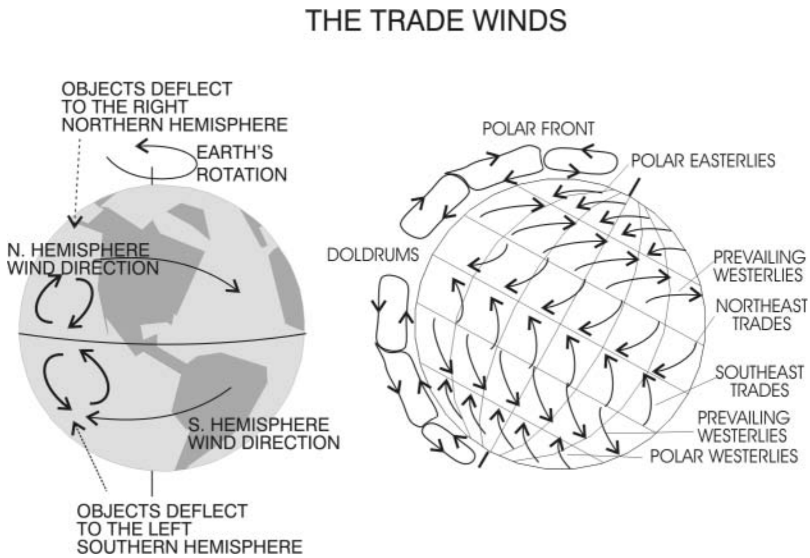


Figure H2. The trade winds were used by sailing ships to head west carried by the prevailing winds at a lower latitude in the northern hemisphere and return westward at a higher latitude.

air thus causing a circulation that was continuous with the cooler air moving under the less dense hotter air. The cooler air replaces the warmer air causing masses of air moving in giant patterns of circulation. This circulation, regardless if it is in a room where the air is heated with a stove or for giant air masses in the atmosphere, the air will continue to circulate as long as there is a difference in the temperatures of two masses of air. At warmer climate regions the heated air is "pushed" up by the cooler heavier air, heating up the air as it rises. This circulation of cool air from northern latitudes moving close to the surface of Earth toward warmer southern latitudes near the equator forms a pattern known as a "cell." The warm air mass then moves toward the higher cooler latitudes where they are again cooled as the circulation continues as long as Earth is warmed by the sun. This movement of air masses creates a circulation that is now called a "Hadley cell" (*see* Figure H1). The Hadley cell carries heat and moisture from the tropics to the more northern latitudes. Hadley was perplexed as to why this moving air did not take a direct path to the poles from the equator. Instead the air moved westward as it proceeded north.

He proposed a theory for the cause of the westward motion in the northern hemisphere of the winds known as the *northeasterly (NE) trade winds*. Hadley believed that Earth's rotation played a crucial role in determining the direction of the large mass of heated air from the tropics (*see* Coriolis' Effect). This circulation of tropical air mainly occurs between 30°N and 30°S latitudes as the hot, moist air from the tropics sinks at higher latitudes as it becomes cooler. The cycle is completed as the cooler air returns to the equatorial tropics, is again heated, and continues the cycle. The Hadley cell explained the westward flow of air at these low latitudes, but not why the wind changed directions at latitudes greater than 30°N. The 30° latitude in the northern hemisphere became known as the "horse latitude." A similar cell to the Hadley cell called the *Ferrel cell* is formed at latitudes greater than 30° north. The wind changes direction in the Ferrel cell and flows from north to south. The Coriolis effect causes the winds north of the horse latitudes to flow eastward. It might help to remember that when meteorologists refer to the "NE trade winds" they are referring to the direction from which the winds are flowing. This means the NE trade winds are flowing from east to west. The opposite is true for the westerly winds north of the horse latitudes that are flowing from west to east. At warmer climate regions the heated air is then "pushed" up by the cooler heavier air, heating up the air as it rises.

See also Coriolis

> The horse latitudes are regions in the subtropics between 30° and 35° in the Northern and Southern Hemispheres. The air in these regions is relatively dry and thus exhibits high air pressures that produce weak or no winds. (Note: the lower the air pressure, the more severe are storms with winds.) Sailors, particularly in the Northern Hemisphere, called this region around 30° latitude the ''horse latitudes'' because sailing ships would be stuck in a calm area for days. If the calm lasted for many days and water and food for the horses and cattle on board were running low, the sailors would throw the animals overboard so they would have enough water to survive until the ship moved out of the calm area. There is no explanation of why they just didn't eat the animals. Interestingly, many of the dry and desert regions of the world, including the great Sahara desert, also lie in the horse latitudes. Because this latitude is also near the Tropic of Cancer (in the Northern Hemisphere and Tropic of Capricorn in the Southern Hemisphere), it is also known as the Calms of Cancer or Calms of Capricorn.
>
> This information on the direction of air movements was extremely important during the days of sailing ships. Sailors now knew the reason they must take a more southerly route to the New World and a more northerly route to return to Europe. Hadley, a well-known and respected lawyer and amateur meteorologist was elected a fellow in the Royal Society in 1745. The Hadley Centre for Climate Prediction and Research in England, as well as a crater on the planet Mars, are named for him.

HAECKEL'S BIOLOGICAL THEORIES: Biology: *Ernst Heinrich Haeckel* (1934–1919), Germany.

Haeckel's law of embryology: *Ontogeny recapitulates phylogeny.*

Ernst Haeckel spent his professional adult life attempting to use the concept of evolution as a means to develop a unifying theory for the field of biology. He contended that the embryological stages of all animals were a recapitulation of their evolutionary history. *Ontogeny* is the embryonic development of organisms, while *phylogeny* is the evolutionary history of a species. Haeckel also believed that at one time there were animals on Earth that resembled all the developmental stages of the embryos of animals presently found on Earth. In other words, he incorrectly believed there were prehistoric mature animals that resembled the embryos of modern animals. Haeckel hypothesized that the mechanism for inheritance of traits was present in the nuclei of cells, even though he was unaware of chromosomes, genes, and DNA. There is some relationship to the similarities of early stages of development of animal embryos in that the cell nuclei of all animals contain a very large proportion of the same DNA. Mammals, including humans, share approximately 95% to 98% of the same DNA, and chimpanzees and humans share about 99% of the same DNA. Although it was partially supported by Stephen Jay Gould, most biologists no longer accept Haeckel's recapitulation theory (*See also* Gould).

Haeckel's theory of evolution: *All animals are derived from inanimate matter.*

Haeckel developed a hierarchy evolution design based on the premise that all animal matter was derived from inanimate matter and then progressed upward to humans.

Haeckel observed that there was a direct relationship between and among plants and animals and the environments in which they lived. Like many before him, he observed that there seemed to be a symbiotic relationship between animals and their environment. In 1868 Ernst Haeckel coined the word ''ecology'' to describe the study of plants and animals and their relationship to each other and their environment: the soil, water, atmosphere, light, heat, oxygen, carbon dioxide, and all the other elements in their biological surroundings. Ecology is, in essence, a study of interrelated ''systems'' of living organisms and their inorganic environments. The term *ecology,* from the Greek work *oikos,* meaning ''household,'' is from the same root word as *economics.* Ecology was not a recognized science until the early part of the twentieth century. Many people confuse environmentalism (an ideological political movement) with ecology (a science based on systems).

He came to this conclusion from the scientific concept of symmetry and proposed his inorganic origin of animal life by relating the symmetry of the simplest animals to the symmetry of inorganic crystals. Although this theory as related to evolution is not now accepted, there is some acceptance of the idea that, at some point in history, inorganic chemical elements combined to become self-replicating, prebiotic organic molecules. These reproducing molecules are assumed to have developed into primitive DNA and cells. This is one theory for the origin of life.

Haeckel also contended all higher multicellular animals (chordates) with three layers of cells (ectoderm, mesoderm, and endoderm) were derived from animals, such as jellyfish and sponges and other marine invertebrates (gastrula), which are composed of only two layers of cells (ectoderm and endoderm). He was the first to distinguish protozoa (single-celled animals) from metazoa (multicellular animals).

Haeckel's concept of social Darwinism: *Human culture and society conform to the laws of evolution.*

Ernst Haeckel, an ardent supporter of Darwin's concept of organic evolution, predated current social Darwinists, such as Edward O. Wilson, by several decades. Haeckel's concept of social Darwinism asserts that human society is as much a product of nature as is human anatomy and physiology, and thus is no different from other organisms. In other words, natural selection applies as much to human behavior, cultures, societies, and religions as it does to the nature of the organism. This concept is not fully accepted by all biologists, partly because it is seen as antireligious and places humans in the same category as other animals and partly because it is used as a rationale for **eugenics**.

See also Aristotle; Darwin; Dawkins; Gould; Wallace; Wilson (Edward Osborne)

HAHN'S THEORIES OF NUCLEAR TRANSMUTATIONS: Chemistry: *Otto Hahn* (1879–1968), Germany. Otto Hahn received the 1944 Nobel Prize for Chemistry.

Hahn's and Meitner's nuclear isomerism: *Nuclei of different radioactive elements exhibit identical properties.*

Otto Hahn discovered a new radioactive form of the element thorium (Th) which he called "radio-thorium," and Lise Meitner discovered protactinium (Pa). Radioactive isomerism is defined as the phenomenon that occurs when some radioactive elements with the same atomic number (number of protons) and the same number of neutrons in their nuclei possess different properties and behave in different ways from the nonisometric forms of the same element. Interest in the concept of isomerism resulted in the collaboration between Hahn and Meitner. In other words, an isomer of an element has exactly the same atomic number and mass but not the same characteristics. This discovery for radioactive elements led to their more important discovery.

Hahn–Meitner–Strassman theory of nuclear fission: *Nuclear transmutation occurs in heavy as well as lighter elements.*

Ernest Rutherford first discovered the transmutation of the nucleus of one element into the nucleus of another element—one that has a nucleus with a different atomic number and mass—when he observed oxygen being transformed into nitrogen. Marie and Pierre Curie discovered similar reactions with uranium and radium. Hahn and his collaborators theorized there are two important aspects to nuclear transmutation. First, these types of nuclear reactions always emit light beta particles, high-energy electrons, and/or heavy alpha particles (helium nuclei). Second, the transmutation of one element's nuclei to form different nuclei occurs only between elements that are more than two places apart on the **Periodic Table of the Chemical Elements.** Hahn noticed these rules did not apply to heavy elements when he used heavy atomic nuclei (neutrons and alpha particles) to bombard uranium, which turned into lead. He also bombarded the heavy element thorium with neutrons. He then theorized there must be an intermediate emission of particles and lighter elements involved in stages between the uranium and lead. In essence, Hahn split the uranium atom by bombarding it with neutrons, thus opening the door to research in developing a fissionable chain reaction and later the atomic bomb and the generation of electricity and useful isotopes by atomic reactors.

See also Curie; Frisch; Meitner; Rutherford

HALDANE'S THEORIES OF GENETICS, EVOLUTION, AND ORIGINS OF LIFE: Biology (Genetics): *John Burdon Sanderson Haldane* (1892–1964), England.

> *Genes follow a rule for sex determination in hybrids, meaning that for the first generation of offspring between two different species, the sex genes are recessive and the hybrid will not develop as an embryo or, if born, will be sterile.*

Haldane was the founder of what is known as population genetics, but his main discovery was a rule that determines the sex of a hybrid animal. Haldane's rule described the well-known example of hybrid inviability and sterility. He noticed that an offspring between a male and female of different species was either stillborn, or when a live birth occurred, the sterile offspring displayed only one sex, usually heterogametic (XY) rather than homogametic sex (XX or YY). In essence, the rule states that if one particular sex is born of mating between a male and a female of different species, their offspring, if living, will be a hybrid whose sex is heterogametic. This means the offspring will most likely be male because males provide the sexual differentiation, which is the evolutionary path to differentiation and formation of new species. Haldane was intrigued by human genetics. He even prepared a map of the X chromosome with the genes that cause color blindness.

Mathematics can be used to explain population genetics and evolution.

Although there were other biologists interested in the premise that mathematics can be used to develop a theory of population genetics, it was Haldane who published a series of papers indicating that there is a direction and rate of change of the genes related to mutation and migration. One paper was titled "Mathematical Theory of Natural and Artificial Selection." Another paper titled "The Causes of Evolution" was a compilation of his research on population genetics that strongly supported and strengthened Charles Darwin's theory of natural selection as the primary operator of evolution. He was the first to explain evolution and natural selection in mathematical terms as related to Mendelian genetics.

John Haldane was interested in science from an early age and assisted his father, a physiologist, in setting up and conducting experiments in his father's home laboratory. While in the military in World War I, he was twice wounded. He became interested in research with respiration and its related chemistry after the Germans used poison gases on Allied forces. This led him to work on the development of an improved gas mask. He held positions in several British universities where he established his reputation in human genetics. He also was a member of the British Communist party and made political speeches. He moved to India permanently in 1957, ostensibly in protest of Britain's participation in the invasion of the Suez Canal.

During his extensive research studies he experimented on himself, acting as a guinea pig. One experiment involved exposing himself to extreme levels of oxygen. This caused a severe reaction that led to a seizure that damaged his spinal cord. In another experiment he used a pressure chamber to rapidly decompress his body and ruptured both eardrums. In yet another experiment he inhaled carbon dioxide to see how it affected muscles related to respiration. He also drank a mixture of $NaHCO_3$ (sodium carbonate) and NH_4Cl (ammonium chloride) that produced hydrochloric acid in his blood, the object of which was to observe the changes in the levels of sugar and phosphate in his blood and urine.

Haldane's theory of the origin of life: *Assuming Earth's original atmosphere was a mixture of ammonia, hydrogen, methane, and water vapor, these factors were sufficient to cause the formation of organic compounds, which were then deposited in the oceans.*

These early oceans were more like a hot, dilute soup that further evolved into complex organisms. This theory and research is related to the later studies and experiments carried out by Harold Urey and Stanley Miller at the University of Chicago where they used such a mixture and a high-energy spark to simulate lightning. They did produce some amino acids that are the building blocks of life, but not life.

After Haldane's move to India in the late 1950s, he was able to do extensive research on genetics. He wrote over three hundred papers and articles for scientific and political publications including the communist *Daily Worker*. He became an Indian citizen in 1961. He died of cancer in 1964, but not before writing a series of humorous poems that chronicled the challenges of the disease that killed him.

See also Darwin; Kimura (Motoo); Mendel; Miller; Urey

HALE'S SOLAR THEORIES: Astronomy: *George Ellery Hale* (1868–1938), United States.

Hale's sunspot theory: *The spectra of sunspots can be used to identify the elements in the outer reaches of the sun.*

George Hale spent most of his life seeking funds to build larger and larger telescopes. His efforts resulted in the forty-inch telescope at the Yerkes Observatory on Geneva Lake in Williams Bay, Wisconsin; the sixty-inch reflector telescope and the

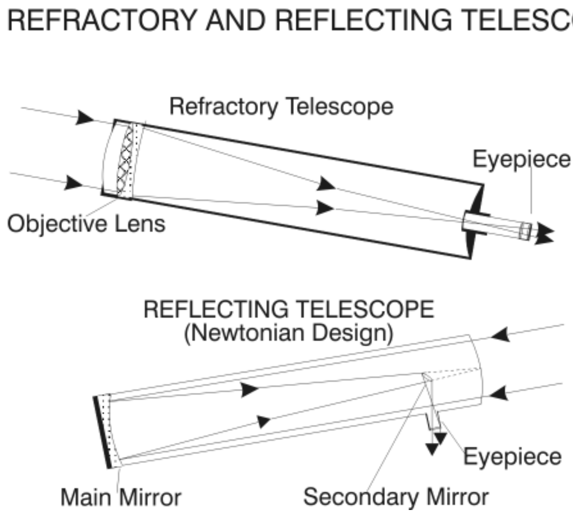


Figure H3. Diagrams of the refractory and the reflecting telescopes. The size of the refractory telescopes is limited by the distortions in large glass lenses. Reflecting telescopes collect more light from objects by use a parabolic mirror, which can be made larger than a glass lens.

100-inch Hooker telescope, both installed at the Mount Wilson Observatory located in the San Gabriel Mountains of Southern California; and finally the 200-inch Pyrex mirror reflecting telescope installed at the Palomar Observatory in north San Diego County, California. Hale spent the last years of his life supervising the construction of the 200-inch telescope at Palomar and the buildings associated with it. He was one of the few astronomers who realized that bigger and more powerful telescopes were needed to advance the study of astronomy. Some of these telescopes were of the *refractor* type that uses a series of lenses, while the larger instruments were of the *reflector* type, which use mirrors (*see* Figure H3).

An instrument he invented, called the *spectroheliograph*, enabled him to photograph and make measurements of sunspots. He viewed and photographed small bands of wavelengths of the sun and identified the double spectral lines emitted by the element calcium, which led to the study of the chemical makeup of the outer layers of the sun. Hale used his progressively more powerful telescopes to effectively prove that the Martian "canali" (canals) reported by Schiaparelli are nonexistent.

Hale's hypothesis for extraterrestrial magnetic fields: *Sunspots exhibit strong electromagnetic fields.*

About ten years after using his spectroheliograph to describe the chemical elements in sunspots, George Hale identified the Zeeman effect, which occurs when the magnetic field splits the spectral lines of light from the sun, enabling the viewer to detect specific elements in the sun. This was the first time that a magnetic field was detected as originating from another object beyond Earth. The so-called sunspot cycle is an irregular cycle of about eleven years between the high and low portions of the frequencies of the cycles.

See also Lorentz; Schiaparelli; Zeeman

The story of the conception, funding, and construction of the 200-inch Hale Telescope located in the Mount Palomar Observatory is fascinating. Hale had secured funding for earlier smaller telescopes located in various institutions. He sought funds for the construction of his dream of a giant reflecting telescope from the Rockefeller Foundation. In 1929 the foundation agreed to donate $6 million to the California Institute of Technology. Hale was appointed chairman of the group responsible for its completion. The task proved challenging. The first 200-inch mirror that cost $600,000 was a failure due to imperfections and distortions in the glass. Hale suggested they use a new type of glass called Pyrex and the first mirror cast with this new type of heat resistant glass was successful in 1934. It weighed sixty-five tons and required several months to cool under controlled conditions. The giant disk was shipped from the Corning Glass Works in New York to California on a special truck that never accelerated more than twenty-five miles per hour. The grinding of the parabolic Pyrex disk to form the reflecting mirror was delayed during World War II. By the time it was completed and commissioned as the Hale telescope in 1948, George Hale had been dead for nearly a decade. Although other larger, as well as satellite telescopes have been developed, the Hale continues to be a very impressive and productive instrument.

HALLEY'S THEORIES FOR COMETS AND STARS: Astronomy: *Edmond Halley* (1656–1742), England.

Halley's theory for the return visits of comets: *Gravity that affects the planets also affects the paths of comets.*

Edmond Halley not only accepted Newton's laws of motion and gravity, but he was such a staunch advocate of these laws that he provided funds for the publication of Newton's famous publication *Principia*. Halley managed to upset John Flamsteed (1646–1719), his predecessor as royal astronomer at the Greenwich Observatory, by allowing Newton to publish Flamsteed's astronomical observations before Flamsteed, Britain's first Astronomer Royal and founder of the Greenwich Observatory, had completed them.

Halley theorized that comets must react similarly to planets because comets are also affected by the gravitational attraction of the sun. He collected data for several past comet sightings and noted there appeared to be repetition in the number of years for the sightings. He then calculated that the comets of the years 1456, 1531, 1607, and 1682 were actually the same comet that traveled in a large, elongated ellipse around the sun. Using this seventy-six-year cycle, he predicted the same comet would reappear in the year 1758. Halley died before he could see his comet return, but it was named after him and ever since has been known as Halley's Comet. The same comet was first viewed and recorded in the year 240 BCE. The most recent visit was in 1986, and the next is expected in 2061 or 2062.

Halley's theory of stellar motion: *Stars are not fixed, and their movements can be detected over long periods of time.*

Ancient stargazers, as well as the Greek astronomers, recorded the positions of the brightest stars. Many years later, Edmond Halley also catalogued the positions of three of the brightest stars: Sirius, Procyon, and Arcturus. He noted their positions had changed, and thus stars must not be in fixed positions. Due to the great distances of stars from Earth, any movement of a star is difficult to observe. Halley felt the great astronomer Tycho Brahe had made the best measurements of these same stars' positions, but at that time Tycho was unaware of their slow apparent movement due to the tremendous distances of the stars from Earth. Comparing his own records with Tycho's data, Halley established the fact that the real motion of the stars was detectable only after long periods of viewing. Later astronomers used the concept of parallax, where the position of a star is measured at six-month periods as Earth revolves around the sun, but these measurements made over a short period of time did not detect star motion. Thus, it was determined the movement of stars was random. It was not until the early 1900s that the Dutch astronomer Cornelius Kapteyn observed that two different streams of stars were moving in opposite directions. This proved that the movement of stars was not random but rather proceeded with some order, as was discovered in galaxies that continue to move away from us and from each other at increasing velocities.

Edmond Halley, the first to study the stars in the Southern Hemisphere, also identified two "cloudy" areas, one named the Magellan Cloud, and the other a star group referred to as the Southern Cross. He developed meteorological maps and found that the subtropical trade winds blow from the southeast toward the equator in the Southern Hemisphere and from the northeast in the Northern Hemisphere. (Early sailors, including Christopher Columbus, understood this occurrence and made use of the trade winds when crossing the Atlantic Ocean eastward below the Tropic of Capricorn and returning to Europe north of the Tropic of Capricorn.) Halley correctly related this phenomenon to a major circulation in the atmosphere due to the difference in the heat produced by the sun in the areas above and below the equator as affected by the rotation of Earth.

See also Coriolis; Hadley

HALL EFFECT OF ELECTRICAL FLOW: Physics: *Edwin Herbert Hall* (1855–1938), United States.

An electric force is generated when a magnetic field is perpendicular to the direction of an electric current. This force is perpendicular to both the magnetic field and the current.

A more technical explanation is that a transverse electric field will develop in a conductor that is carrying a current while it is in a magnetic field. The Hall effect occurs when a magnetic field is at a right angle to the direction of the current flow. This modulates and multiplies voltages and can act as a magnetic switch for semiconductors, which is important for electronic applications. These devices, also referred to as *Hall generators*, are used in brushless induction motors, tachometers, compasses, thickness gauges, and magnetic switches that do not require contact

> Edwin Hall received his PhD degree from the Johns Hopkins University in Baltimore, Maryland, in 1880. Soon after, he joined the Harvard faculty and was appointed professor of physics in 1895. He remained in this position for twenty-six years. While working on his doctorate related to electric currents within a magnetic field, there was a controversy as to whether there was action on the electricity itself or just on conductors carrying the electricity. He set up a unique experiment using thin sheets of gold foil to detect that the electric potential was acting perpendicular to both the current and magnetic field. The peculiar effect was soon named the Hall effect and is explained as: When an electric charge is moving in a conductor, it will experience a transverse force that tends to move the flow of current to one side of the conductor. The Hall effect has many applications in modern electronics industries, as well as in electric and magnetic equipment. Almost one hundred years after Hall's experimental evidence for this effect, the 1985 Nobel Prize for Physics was awarded to Klaus von Klitzing for his additional work on this phenomenon.

points. Devices employing the Hall effect can detect minute hairline cracks in the wings and bodies of airplanes, as well as in very sensitive instruments that can measure weak magnetic fields.

See also Ampère; Faraday; von Klitzing

HAMILTON'S MATHEMATICAL THEORIES: Mathematics: *Sir William Rowan Hamilton* (1805–1865), Ireland.

Hamiltonian functions: *A special function of the coordinates and the moments of a system is equal to the rate of change of the coordinate with time.*

Sir William Hamilton worked out the mathematics expressing the sum of kinetic and potential energies of any dynamic (changing) system. It is related to the Hamiltonian principle, which states that the time integral of the kinetic energy minus the potential energy of a system is always at a minimum for any process. The equation involves both the motion and time for the system. The Hamiltonian function was an important step in developing the theory of quantum mechanics.

Hamilton's quaternions: *By ignoring the products of multiplication, a system of internal algebra for ''hypercomplex'' numbers can exist for ''quaternions'' (Latin for ''four'').*

In developing his theory, Sir William Hamilton applied algebraic functions to non-Euclidean geometry involving *n*-dimensional (multiple dimensions) analytic geometry, which involves more than the three dimensions (x,y,z . . . ,n) of space. The quaternion is a hypercomplex number in algebra. It has always been accepted that $A \times B = B \times A$, but for quaternions, the commutative law of multiplication does not hold. Therefore, $A \times B$ does not necessarily equal $B \times A$. The quaternion theory is important in the field of abstract algebra, but it has little use in physics, where vectors are more applicable. However, it did lead to the development of mathematical matrices, such as matrix mechanics as applied to Werner Karl Heisenberg's quantum theory. Hamilton made other contributions to optics, mathematics, and abstract algebra.

See also Heisenberg; Lagrange

Sir William Rowan Hamilton had an interesting, if somewhat tragic life. He was introduced to mathematics at the age of thirteen when he studied algebra. At age fifteen he found an error in a work published by Laplace. At age eighteen he entered Trinity College in Dublin, Ireland, where he showed interest in the classics and mathematics. While at Trinity College, he was introduced to a friend's daughter, Catherine, with whom he carried on a love letter romance for most of his life. When her mother decided that she should marry a much older and well-to-do man of the clergy who could provide for Catherine, an extremely upset Hamilton became ill, read and wrote poetry, and considered suicide.

In 1826 during his senior year at Trinity he received an unusual honor in both the classics and mathematics. This was somewhat unusual because he seldom attended classes. Soon after graduation he was appointed professor of astronomy at Trinity College even though he lacked experience as an observer of the heavens. Although still smitten with Catherine, he married a local woman, Helen Maria Bayly, who was often ill. He continued his work because he had two children with Helen, but his failed marriage soon led to heavy drinking. It is reported that in 1843 as he was walking on his way to the Royal Irish Academy he was thinking about his concepts of noncommutative algebra called ''quaternions'' (four). He is said to have carved the formula for quaternions in a stone on the Brougham Bridge. It was: $i^2 = j^2 = k^2 = i\ h\ j = -1$. Hamilton and Catherine kept in touch with each other which neither spouse seemed to mind. Hamilton presented Catherine with his book of *Lectures on Quarternions* just two weeks before she died.

HARDY'S MATHEMATICAL THEORIES: Mathematics: *Godfrey Harold Hardy* (1877–1947) England.

The Hardy–Weinberg law: *The allelic frequencies in a population remain the same in subsequent generations.*

Note: An **allele** is a particular pair of genes (or group of genes) located at the same position on a chromosome.

This law is related to population genetics that states mathematically that inherited characteristics are of more importance to a population of organisms than inheritance is to individuals. It is well known that populations evolve from environmental changes by natural selection. But it is an allele of a group of genes that determines the specific characteristics of an organism, such as height, color, and so forth. When a gene mutates (alters), it may pass from parent to offspring. If these new (mutated) genes increase the frequency of successful change in future generations, there will be evolution of the population. The Hardy–Weinberg law is, in essence, a statement for an *equilibrium equation* that states that if no factor interferes with the allele frequencies in a population, evolution will not occur. However, there are forces that change allele frequencies such as mutation, mate selection, migration, and drift. The Hardy–Weinberg law is named in honor of Godfrey H. Hardy, called "Harold" by friends and colleagues, and Wilhelm Weinberg (1862–1937), a German physician, who independently and in the same year (1908) formulated the identical principle of population genetics.

Godfrey Hardy was educated at Cambridge University, Hampshire, England, and at Trinity College, one of the constituent colleges of the University of Cambridge. After graduation he became a fellow in mathematics in Trinity College but left in 1919 to take the Savilian Chair of Geometry at Oxford University. He returned to Cambridge n 1931 to become the Sadleirian Professor of Pure Mathematics, a position he held until 1942. (The Savilian Chair was established in 1619 by Sir Henry Savile; the Sadleirian Chair was established by Lady Sadlier in 1701.) Hardy's main interests were in the theory of numbers, inequalities, integrals, complex functions, and the Riemann zeta-function. In addition to his work in pure mathematics, he was considered an excellent teacher who introduced modern mathematics to several generations of British students. He sponsored a brilliant Indian mathematics student Srinivasa Ramanujan (1887–1920) for a scholarship at Cambridge in 1914. They became close friends as Hardy mentored and tutored Ramanujan. In an interview, Hardy is reported to have said that his discovery of and collaboration with Ramanujan was the one romantic period of his life. He was known as an eccentric who enjoyed cricket games, was an outspoken critic of Christianity, and refused to have his picture taken—there are only five photos of him in existence.

Hardy investigated many areas of pure mathematics and published multiple papers in collaboration with many other mathematicians in areas such as the Riemann zeta-function, prime numbers, the Fourier series, divergent series, Diophantine analysis, and complex analysis. Explanations of his mathematical studies are beyond the scope of this book.

See also Fermat; Fourier; Hamilton; Lagrange; Laplace

HARKINS' NUCLEAR THEORIES: Chemistry: *William Draper Harkins* (1873–1951), United States.

Harkins' rule for isotopes: *The isotopes of elements that have odd-mass numbers are less abundant than are the isotopes of elements with even-mass numbers. Both are represented by whole number ratios for their atomic numbers and weights.*

William Harkins proposed the whole number rule about the same time as Francis William Aston. The rule determined that the mass and the occurrence of isotopes of stable elements are related. When isotopes of stable elements are considered, the numbers of neutrons in the nucleus are related as whole numbers—never fractions of neutrons. Harkins predicted both the existence of the neutron and the element deuterium (heavy hydrogen whose nucleus contains a neutron as well as a proton (*see* Figure O1 under Oliphant). Using a mass spectrometer, which he invented, Aston determined this whole number concept was not always correct. Sometimes the mass of isotopes was slightly more or less than a whole number. Aston called this the *packing fraction*, which occurs when the hydrogen nuclei join to form helium nuclei (fusion) and a small amount of energy is produced. Therefore, Harkins' whole number rule was modified to conform to new experimental data.

Harkins' theory for the hydrogen-helium-energy reactions: $4H_1 \rightarrow He_4 + \textit{energy}$.

Marie Curie demonstrated the concept of radioactivity produced by the fission of nuclei of radioactive elements, resulting in the production of enormous amounts of energy. However, it was William Harkins who applied his knowledge of isotopes and neutrons to address Aston's "packing fraction" principle to determine how hydrogen could be converted into helium with a tiny fraction of matter converted to energy. This confirmed the basic laws for the conservation of matter and energy. It was later determined that such a conversion reaction maintains the energy output of the sun and other stars. It was not until several decades later that the concept was applied beyond the laboratory, resulting in nuclear energy to produce electricity, isotopes, and the atom (nuclear) bomb.

See also Aston; Curie; Fermi; Rutherford; Urey

HARVEY'S THEORY FOR THE CIRCULATION OF THE BLOOD: Biology: *William Harvey* (1578–1657), England.

> *The beating heart propels blood through the arteries, where, after it reaches the body's extremities, it is then circulated back to the heart through the veins.*

From the time of Galen (second century CE), medical practitioners taught that blood was produced in the liver. Then in the seventeenth century, William Harvey concluded that for this to be true, a tremendous amount of new blood would have to be produced continuously by the liver to maintain a constant flow. Thus, he theorized the same blood must circulate through the blood vessels. Harvey dissected cold-blooded animals to observe the pumping action of their hearts. Because circulation is slower in frogs and snakes, he observed and traced the blood passing from the right to the left side of the heart through the lungs, not through "pores" in the septum (tissue that divides the two sides of the heart), as was taught and believed from the days of Galen. Harvey observed that as the heart beats, **systolic** contractions occurred, swelling the arteries with blood as it was pushed throughout the arterial system of the body. At the **diastolic** phase, the heart was again filled with blood that was returned by the veins. Harvey declared the heart to be a pump. This established his theory that the heart caused the blood to circulate throughout the body via the arteries and then back to the heart through the veins. Nonetheless, no reasonable explanation existed for how the blood was transferred from the ends of the arteries to the veins to complete the circuit back to the heart. Harvey correctly theorized the presence of very small blood vessels, too small to be seen, that provided the passage of blood from the ends of arteries to veins. The validation for Harvey's discovery had to wait until the invention of the microscope and Marcello Malpighi's observance of the tiny web of blood vessels in the thin skin of a bat's wing, which he named *capillaries* (Latin for "hair-like").

See also Galen

HAÜY'S GEOMETRIC LAW OF CRYSTALLIZATION: Geology and Mineralogy: *René Just Haüy* (1743–1822), France.

All minerals exhibit six different basic forms dependent upon how the molecules are joined to produce crystals.

Haüy's law of crystallography was a more-or-less serendipitous discovery that happened when he dropped a piece of calcite spar (calcium carbonate $CaCO_3$) crystal that shattered in many smaller pieces. Being a mineralologist, he recognized the odd patterns of the fragments with smooth surfaces that met at similar angles as being rhombohedral in shape (a rhombohedron figure may be thought of as a "stretched" out cube with six faces). He was also familiar with the work of Nicolaus Steno in the late 1600s who discovered that the angle between faces of a particular crystal are similar, as well as the works of Robert Hook, Christiaan Huygens, and Sir Isaac Newton who all considered that crystals are compiled of stacks of particles, similar to a stack of bricks. Therefore, Haüy hypothesized that crystals were formed in layers that are now called *unit cells*, and that, as a whole, the crystal was formed by different geometric shapes (*see* Figure H4).

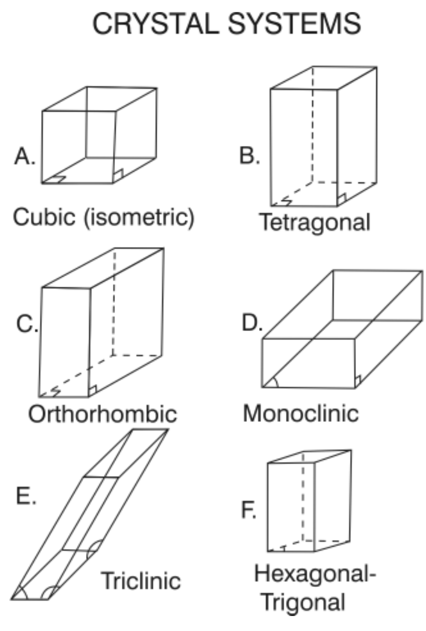


Figure H4. Various chemical changes result in different arrangements of the particles of crystals, resulting in different structures and thus a variety of basic shapes.

After more investigation, he decided that chemical changes were responsible for the differences in shapes of crystal minerals. Haüy expressed his work as a mathematical theory in his writings, which impressed the scientific community. In addition, he experimented with *pyroelectricity* (to heat) that is the generation of an electric current by heating a crystal (this is related to, but not the same as, *piezoelectricity*, that means "to press"). Both of these processes are used today in the form of thin films of semiconducting compounds. One example is a heat-detecting device to identify the heat from a human or animal body just a few feet away and convert this into an electrical signal. Another is to use $LiTaO_3$ (Lithium tantalite), that has both piezoelectric and pyroelectric properties and is used to create an experimental small-scale nuclear fusion known as "pyroelectric fusion."

Haüy was arrested during the French Revolution and almost lost his life in prison. However, later during Napoleon's rule he was released, whereupon he became professor of mineralogy at the French National Museum of Natural History in Paris. But again, disaster overtook him during the period of the Restoration government. He ended his life in poverty, but he will always be known as the father of mineral crystallography and for maintaining his self-respect right up to the end of his life.

HAWKING'S THEORIES OF THE COSMOS: Astronomy: *Stephen William Hawking* (1942–), England.

Hawking's theory for the nature and origin of the universe: *Applying the submicroscopic theory of quantum mechanics to the macroscopic universe produces a wave function similar to a wave function for elementary particles, thus shaping the nature of the universe.*

Stephen Hawking theorized that according to the quantum wave function theory, as related to Einstein's theory of relativity, there is no past or future because the time function exhibits characteristics of special dimensions (relativity). The universe can, by its own accord, be both zero in size or infinite in size. It can have no beginning or no ending. This led Hawking to a new version of "open inflation" that spontaneously created a "bubble" out of nothingness. In other words, the big bang, which is generally accepted as how our universe began, had to have something with which to start. Hawking's use of quantum mechanics provides this answer by showing how the wave function starts as a *singularity* (a region of space-time where one or more components of curved spaces become infinite.)

These ideas preceded the three different geometries or shapes for the universe. The first concept maintains the universe is flat space as related to the rules for Euclidean geometry, in which parallel lines never meet or cross, a triangle always has exactly 180° as the sum of its angles, and the length of a circle is its circumference (two times pi × the circle's radius or $2\ \pi r$). Although the space in the universe generally is considered flat, space-time is not. For most of our science and measurements on Earth, three-dimensional space involves L for length, L^2 for area (length × height), and L^3 for volume (length × height × width, or depth). Astrophysicists add time (T) as the fourth dimension to the three dimensions of space to describe matter in relativistic terms. In other words, the structure of matter changes in space over long periods of time—thus, the term "space-time." Contrary to older theories, the universe is not static but rather is a dynamic, changing physical entity. This also means that over great distances and long periods of time, the extended universe will not remain flat. At its outer reaches, the total curvature of space-time is determined by the density of matter as well as the time involved for the continued expansion of the universe. An analogy: When standing on the surface of Earth and looking toward the horizon, for about a mile the surface seems flat, just as the space near us that we can see seems flat. But when viewed from a spacecraft, earth looks curved—just as the distant sectors of the universe also appear to be curved.

The second theory for the geometry of space is that space is spherical similar to a globe. This represents a closed universe, which is similar to Einstein's original static universe theory. Curved surfaces are positive in the sense that space curves back on itself similar to the surface of Earth. Because a closed universe is finite, parallel lines would always converge (e.g., line of longitude for Earth); the sum of the angles for a triangle laid out on the surface of a sphere is always greater than 180° (the sum of the angles for a triangle can total up to 540° when projected on the surface of a sphere). And the circumference of a circle inscribed on the globe's surface is always *less* than $2\pi r$.

The third geometry is a hyperbolic "open" universe whose negative surface would look something like a horse saddle. In an open universe, parallel lines would diverge and never meet, the sum of the angles for a triangle would be less than 180°, and the circumference of a circle inscribed on its surface would be *greater* than $2\pi r$. Before astronomy became a science, the closed geometry theory was usually accepted, despite the fact that this implied a finite, static, unchanging universe, which is inconsistent with the observable evidence. According to the latest research, the flat universe theory is the most unlikely geometry for the actual universe.

Hawking's black hole theory: *Mini black holes, also known as primordial black holes, were formed soon after the beginning of the big bang.*

Stephen Hawking was not the first to advance the black hole theory. John Archibald Wheeler named this phenomenon, which describes the aftermath resulting when a massive star has "burned up" its nuclear fuel. The dying star cools down to almost absolute zero and shrinks below the critical size, meaning its radiation can no longer overcome its internal gravity, resulting in a "singularity" as a bottomless hole represented as a point in space-time. This concept was first known as the *collapsed star phenomenon*. No nearby light or matter can escape the strong gravitational attraction from this bottomless hole—thus, the name "black hole." Einstein's theory of general relativity asserts that gravity is related to the curvature of space-time, and massive objects, such as giant dead stars, distort space-time. This distortion causes an *event horizon* as the boundary for a black hole. Once an object moves close to the ever-expanding boundary, extreme gravity pulls it into the hole for which there is no escape, not even for light. Most black holes seem to be located near the center of galaxies. The more massive a black hole, the larger its size. It can capture and compress many massive stars and might weigh as much as 10^{36} kilograms (10 followed by 36 zeros). On the other hand, there might be smaller black holes (it should be remembered that this concept does not refer to a hole as in an empty hole in the ground; rather, it is an area of compressed mass where light cannot travel fast enough to escape the overwhelming gravity created by one or more collapsed stars).

Hawking expanded the concept of black holes by considering thermodynamics and quantum gravity. Ordinary space is not really empty. It is filled with pairs of particles. Some are positively charged particles that annihilate partners that have negative charges (in space there are pairs of particles and **antiparticles**). Hawking theorized that for black holes, the partner particles become separated, with the negative particle falling into black holes just as all other matter does and the positive antiparticle escaping and giving off energy that can become a real particle or even approach infinity. These particles and antiparticles can exist because of *vacuum fluctuations*, which are fields similar to light, magnetic, and gravity fields. They are also referred to as *virtual particles*. Hawking also theorized that soon after the big bang, many mini black holes existed. They were no larger than the nuclei of hydrogen atoms (protons) and yet weighed billions of tons and produced tremendous energy. Hawking claims that black holes are not 100% black because quantum mechanics caused them to produce particles and forms of radiation at a regular rate. John Wheeler, a theoretical physicist, stated that what falls into a black hole, including ordinary matter such as buildings, cars, or people, is independent of the radiation and thus will come out the same as it went in. Hawking stated that the emission of particles and radiation from a black hole would reduce its mass to the point where it will have zero mass. At this point, the buildings, cars, and people, including information that fell into the hole cannot come out because there is no longer adequate mass for this to happen.

It might be mentioned that in July 2004 Stephen Hawking revised his three decades' old theory of black holes. His new model indicates that black holes do not just "swallow" up objects of matter and radiation, but also send information out of the hole. It seems there are two kinds of black holes: 1) stellar size (the size of stars) that are the leftover stuff of massive dead stars that have imploded and 2) supermassive black holes that have mass greater that a million times the mass of the sun. These are the types of black holes that are found in the center of galaxies and are considered to be related to the processes involved with the way galaxies evolve. There are some smaller black holes that fall between these two categories. It is now also believed that there may be other types of objects that are just the opposite of black holes that are sending matter and radiation into the entire universe. It appears that much more theoretical research is needed before we can completely understand our universe.

Hawking's theories for inflation and singularity: *The original expansion of the big bang was at first rapid, slowing down as the universe aged. The densities of black holes are singularities.*

Before Einstein's theory of relativity, the general concept was that the universe remained the same: it was static. In 1929 Edwin P. Hubble published his measurements that indicated galaxies were receding from Earth and from each other at an ever-increasing rate. Later, Roger Penrose theorized that a collapsing star is a singularity, as are all black holes. *Singularity* means a single point where the density of matter is infinite, just as the curvature of space-time is infinite. It is a region in space where one or more parts of the space-time curvature becomes infinite. It is also known as a single point of a specific function. The concept of singularity is consistent with and conforms to physical laws. On the other hand, space-time, being infinite with no boundaries, is relative; thus there is no beginning or ending to space-time.

Hawking combined quantum theory with gravitation as expressed by Einstein to propose his concept of *quantum gravity*. He then reversed Penrose's singularity theory to explain how the big bang came to be. In other words, there was a singularity—a point in nonlinear time when a single massive point started the expansion of the universe. This expanding universe is explained by the inflation theory, which states that this three-dimensional "spreading" was extremely rapid, causing great heat, radiation, rapidly expanding gases, and energy that overcame gravity at this point. There are several concepts that explain what occurred after this singularity event created the nascent universe. One states that the early rapid inflation of gases slowed and cooled down, and in time these gases (mostly hydrogen) formed helium and the galaxies, stars, planets, and other objects in space. The leftover radiation and matter, galaxies, and stars are still overcoming gravity and thus expanding but possibly slowing down. The quantum gravity theory states that many billions of years from now, there will be a period of deflation that will be caused by gravity taking over again. This scenario is called the *big crunch*, which will end in a new singularity. It somewhat represents the geometry for a closed universe, where gravity finally wins and a collapse occurs. Another theory states that inflation will continue at an ever-increasing rate of expansion, resulting in a lower density of matter in the universe, or new matter will be created continually to maintain the current density of the universe. This scenario represents the geometry for the open universe. The geometry for a flat universe is somewhere between these two extremes, but it best fits the *standard inflationary theory*, which suggests there is much more matter in the universe than we can see or even realize. This so-called dark matter may not be adequate to justify a flat universe theory, but research and speculation continue to find other types of matter or energy in the universe. During the first decade of the twenty-first century, several high-resolution instruments will be placed in orbit to make measurements that will address the many questions and theories related to the origin, nature, and fate of the cosmos.

See also Einstein; Feynman; Hubble; Penrose; Wheeler

HAWORTH'S FORMULA: Chemistry: *Sir Walter Norman Haworth* (1882–1950), England. Sir Norman Haworth and Paul Karrer shared the 1937 Nobel Prize for Chemistry.

> *Carbon and oxygen atoms are linked in specific ratios to form carbohydrate rings of sugar molecules.*

Organic chemistry had succeeded in synthesizing a number of different forms of sugar molecules, mostly linear open-chain structures. Sir Norman Haworth was the first to demonstrate his *prospective formula*, which was his hypothesis leading to closed chains of sugar molecules. He proposed two types of closed rings for molecular sugars. One was the sugar molecule that formed a ring composed of five carbon atoms and just one oxygen atom (glucose), whereas the other consists of the molecular structure for a sugar ring with only four carbon atoms and one oxygen atom (fructose) (*see* Figure H5). By demonstrating that a chain of carbon-oxygen atoms for several types of sugars could be synthesized into rings, Haworth synthesized a variety of polysaccharides (a sugar composed of many monosaccharides) that are produced today.

In addition to his success with synthesizing what is known as the Haworth formula for carbohydrate molecules, Sir Norman Haworth and Tadeus Reichstein independently succeeded in analyzing and synthesizing a variety of vitamins. Their first success identified the substance found in orange juice, which was first called "hexuranic acid." Later, it was identified as vitamin C and named "citric acid" by Haworth. Their discovery enabled the production of synthetic vitamins with the same chemical makeup as natural vitamins. Their work led to a decrease in malnutrition and diseases caused by vitamin deficiencies.

See also Krebs

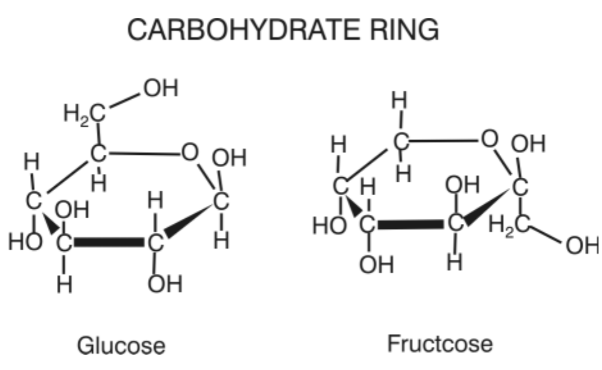


Figure H5. Glucose has 5 carbon atoms in its closed ring sugar molecule, while fructose has just 4 carbon atoms in its closed ring sugar molecule.

HEISENBERG'S UNCERTAINTY PRINCIPLE AND THEORY OF NUCLEONS: Physics: *Werner Karl Heisenberg* (1901–1976), Germany. Werner Heisenberg received the Nobel Prize in Physics in 1932.

Heisenberg's uncertainty principle: *The simultaneous measurement of the position of an electron affects the measurement of its momentum, leading to the uncertainty of either its observed position or movement.*

Werner Heisenberg used matrix mathematics to develop a formulation of quantum mechanics to explain the uncertainty principle as a statistical means to measure the probability of the position and momentum of submicroscopic particles. This principle went a long way toward the development of a formulation of quantum mechanics that was equivalent to the Schrödinger formulation but differed in form (this is analogous to saying the same thing in English and in French). The Heisenberg formulation perhaps emphasizes the uncertainty principle more strongly than does the Schrödinger formulation. Nature at the very small scale has a wavy conformation that can be described only by quantum mechanics. Natural physical laws hold true for everyday objects in the universe, including us. However, in the submicroscopic universe, these same natural laws do not always apply. It is possible for observers to measure accurately the position of a minute, submicroscopic, subatomic particle independently, and it is possible to measure a particle's *momentum* (a vector quality for a particle's velocity × mass) accurately. But both cannot be accurately measured at the same time, thus creating uncertainty. Rather, the small size of their joint uncertainties must be larger than the number referred to as Planck's constant ($\hbar$). Heisenberg insisted the only way to interpret the atom and the subatomic particles that compose them was to observe the radiation (light) they emit. Heisenberg and other physicists developed systems and equations to accomplish this feat. Heisenberg's equation for the uncertainty principle is: $\Delta x \bullet \Delta p \geq \hbar/4\pi$, where Δx is the uncertainty of the particle's position in any direction, Δp is the uncertainty in determining the momentum related to that position, and $\hbar$ is Planck's constant. Statistical probability was used to measure the degree of uncertainty (of a particle's position and momentum) that is related to the development of matrix mechanics that was the precursor to quantum mechanics.

Heisenberg's nucleon theory: *Nucleons are isomers of protons and neutrons.*

Werner Heisenberg also developed the theory that nucleons were composed of neutrons and protons (baryons), which make up the nuclei of atoms. He proposed that both the proton and neutron had approximately the same mass but different spins and thus were forms of **isomers**. Based on his theories of matter, Heisenberg attempted to devise a unified field theory for all elementary

Werner Heisenberg studied under three excellent physicists, Wolfgang Pauli, Max Born, and Niels Bohr. He did his best work in moving fluids. At twenty-five years of age he published an important paper describing the concept of the uncertainty principle for which he is best known. During these early years he published several important papers and at the age thirty-one he received the Nobel Prize in Physics.

During World War II Heisenberg worked with the nuclear physicist Otto Hahn who had shared in the discovery of nuclear fission. Heisenberg became head of Germany's nuclear weapons program. For reasons not completely understood today, the German atom bomb program was not a success. Some say it was more or less sabotaged by the scientists working on the project who may, or may not, have belonged to the secret "Wednesday Society"—the underground resistance group that attempted to assassinate Hitler. Heisenberg's membership in this group has never been proven—one way or the other.

particles that related their characteristics and energies. Neither he, Albert Einstein, nor several other scientists were able to finalize such a grand unification theory (GUT) or a theory of everything (TOE) that would include all submicroscopic particles from the quark up to large molecules, ordinary matter, and all forms of energy, gravity, and the endless universe. (Most theoretical physicists believe that when such a theory is produced, it will be expressed as a simple equation.)

See also Bohr: Einstein; Maxwell

HELMHOLTZ'S THEORIES AND CONCEPTS: Physics: *Hermann Ludwig Ferdinand von Helmholtz* (1821–1894), Germany.

Helmholtz's theory for heat and work: *Heat and work are equivalent, and one can be converted to the other with no loss of energy.*

Hermann Helmholtz was familiar with James Joule's concept of work and heat, and Lord Kelvin's work with thermodynamics. Lord Kelvin later proposed a concept for the conservation of energy. However, Helmholtz was not the first to relate mechanical work to heat. That honor goes to the German physician and physicist Julius Mayer (1814–1878). It might be helpful to define some terms as used by scientists. *Heat* is the result of molecules bumping into each other in random motion. The greater their total motion, the greater the amount of heat. The mechanical equivalent (molecular motion) of heat is measured in calories: 1 calorie = 4.185 joules, while 1 joule = 10,000,000 ergs (the joule is a unit of energy or work). Heat results from mechanical *work*. Try rubbing the palms of your hands together very fast. Note the heat generated from the mechanical motion (work) of your hands. Neither the heat produced by this rubbing friction nor the heat generated by muscle energy that is used to produce this work is lost. Rather, the heat soon disperses into the air around your hands, slightly increasing the motion of air molecules (warming up the air), and is thus conserved. Heat is a form of energy transferred from a body with a higher temperature to a body with a lower temperature—never in the opposite direction (*entropy*). Work is accomplished when a force on a body transfers energy to that body. Work (W) = applying a force (F) over a distance (d) ($W = F \times d$). Work, in the scientific sense, is not exactly the same as in the common sense, which usually refers to some physical or mental effort—although both involve energy and heat. *Energy* is the capacity to do work. Heat and work are forms of energy and are interchangeable. There are many forms of energy, such as heat, light, sound, radioactive, mechanical, work, and so forth; and they are all conserved, but

> Helmholtz also explained his theory on a physical basis by speculating that the total energy of a large group of interacting particles is constant, basing his ideas on the perceptions of Robert Hooke. Using a microscope, Hooke observed the action and interaction of minute particles in a fluid. He related the motion of the particles to heat resulting from what we now know as the molecular action within a body, even before molecular motion was known. Nonetheless, it provided Helmholtz with the idea that work and heat are related. As the law of conservation of energy was refined, it stated that the total amount of energy in the universe is constant. Energy can neither be created nor destroyed, but it can be changed from one form to another. For example, mechanical, magnetic, electrical, chemical, light, sound, kinetic energy, and others are all interconvertible. Also known as the first law of thermodynamics, it is one of the most basic universal physical laws of nature. As did many other scientists, Helmholtz tried unsuccessfully to develop a unified field theory based on his concepts of work/heat/energy, electrodynamics, and thermodynamics.

not in the sense that environmentalists use the word "conservation," usually meaning "saved" and not to be used. In scientific terms, *conservation of energy* or *mass* means that it can be changed from one form to another without any total loss of the original energy/mass ($E = mc^2$).

As a physician, Helmholtz believed animal heat generated by muscle contractions was related to his theory that heat and work are convertible from one to the other in a *quantitative relationship*, with no loss of total energy. This led to the law of conservation of energy, one of the fundamental laws of physics. Imagine yourself raising a baseball from the top of a table to the height of your head. In doing so, you have converted mechanical work to potential energy in a gravitational field. However, you have done the mechanical work at the expense of the energy stored in your body. One might say you did 1 joule of *work*, which is equal to about 0.25 calorie of *heat* because work and heat are forms of energy and interchangeable. You also increased the potential energy of the baseball, which would be released as kinetic energy if the baseball were dropped, resulting in a conservation of energy (none was lost or gained).

See also Carnot; Clausius; Hooke; Joule; Kelvin; Maxwell

HELMONT'S THEORY OF MATTER AND GROWTH: Chemistry: *Jan Baptista van Helmont* (1579–1644), France.

Plants grow, increasing their weight, but without reducing the weight of the soil in which they grow.

Helmont was educated at a Catholic university that specialized in medicine, mysticism, and chemistry, but he refused to accept a degree from the university because the church's teaching conflicted with his beliefs. Helmont established a private research lab in his home and conducted some early experiments on matter and energy. Although many of his conclusions were off the mark, his writings led to more research by others. For instance, the Roman Catholic Church taught, in medicine, that it was possible to treat and heal a wound caused by a weapon by treating the weapon rather than the person's wound. Contrary to church dogma, Helmont stated that this was not a supernatural phenomenon but rather it was a natural phenomenon. He was placed under house arrest for this and other heretical ideas and was prevented from publishing his papers. He also had some odd ideas, such as a belief in the alchemists' philosopher's stone, and that all matter was composed of water (fish were nourished by water). He was one of the first "scientist/philosophers" to record careful observations of nature before drawing conclusions. After his death, his son published most of his works in a book called *Ortus medicinae* in 1648.

Helmont was one of the early scientists who carefully observed and measured well-planned experiments, the most famous of which was the observation of the growth of a specific plant over a five-year period. He noted the specific weight of soil in which it was planted, the plant's growth weight, and the weight of the amount of water it used. At the end of five years, Helmont weighed the plant as well as the soil in which it grew and noted the plant weighed about 165 pounds, but the soil lost less than one-fourth pound in weight. However, he incorrectly attributed all the growth weight to water, which led to a mistaken concept of matter. In another experiment, he burned about sixty pounds of wood, and then weighed the remaining ashes, which equaled less than one pound. He concluded that the lost weight was composed of water and four "gases," which he named *pingue* (methane), *carbonum* (carbon dioxide), and two types of *sylvester* gas (nitrous oxide and carbon monoxide). He was correct that carbon dioxide resulted from combustion as well as the chemical process of fermentation. He also correctly identified the other gases (but not by their current names). Helmont also believed there were several different types of air, just as there were different forms of solids and liquids. He related these "airs" to chaos because they had no specific volume as did liquids and solids, and he coined the term "gas," which soon was accepted along with the common terms "solid" and "liquid," providing a general concept for the three forms or states of matter.

HENRY'S PRINCIPLES OF ELECTROMAGNETISM: Physics: *Joseph Henry* (1797–1878), United States.

Electromagnetic induction: *By moving a conductor through a magnetic field, an electric field is induced in the conductor* (*see* Figure F1 under Faraday).

Solenoid-type magnets were developed and improved in the early part of the nineteenth century. These devices consisted of coils of insulated wire, which produced a magnetic field within the coil when electricity passed through the wire. The English physicist and inventor William Sturgeon (1783–1850) made further improvements when he placed an iron rod inside a coil and observed that, while electricity flowed through the loops of wire forming the coil, the rod became magnetized. However, when the current was turned off, the rod no longer retained its magnetism. Thus, by turning the current on and off, the rod became an on-and-off magnet with the ability to control various mechanical devices. His source of electricity was generated by a battery of simple voltaic wet cells that produce direct current electricity of low voltage (about 1.5 volts for each cell). However, this amount of electricity was adequate to produce electromagnetism, but more current is produced if several cells are connected in series ($8 \times 1.5 = 12$ volts).

The number of turns of wire loops used to form a coil was limited because if any of the bare wires came in contact with each other, they would short out, breaking the electrical circuit. Henry solved this problem by using insulated wires, which could be wrapped close together and overlapped without creating a short circuit, thus producing much stronger electromagnets. He lifted as much as a ton of iron by using a small battery of voltaic cells to supply the electric current. Michael Faraday and Joseph Henry independently proposed the idea that magnetic properties from this coil could be induced to an iron bar. Joseph Henry, who is said to have developed this theory, did not receive credit at first for the principle of magnetic induction because Michael Faraday's findings were published a few months before Henry's. Joseph Henry is immortalized inasmuch as the universal SI constant for inductance is named after him. The Henry SI unit (H) for induction occurs when an electromotive force of one volt is produced when the electric current in the circuit varies uniformly at a rate of one ampere per second.

Henry's concept of an electric motor: *A moving wire that cuts across a magnetic field induces an electric current. Therefore, the process should be reversible.*

Faraday's device used a copper wheel to cut through a magnetic field and thus induced a current to flow through the wire. This later became the concept for the dynamo or electric generator. Joseph Henry questioned what would happen if this process were reversed. He devised a machine with a wheel that would turn when an electric current was sent through the electromagnet. The result was the first electric motor, which over many years of development has become one of the major technological developments of all times. It might be said that Faraday, Henry, and other scientists who worked with electricity and electromagnetism created the laborsaving conveniences of the modern world, that is, using motors that were powered by electricity produced by dynamos (generators).

Henry's concept of "boosting" electricity over long wires: *If a method for maintaining the strength of an electric current over long wires can be found, an electromagnetic communication device could be developed.*

In addition to Joseph Henry, several others imagined an electromagnet solenoid that could open and close a "clicker" circuit using a "key" to send signals through wires. The problem was the natural resistance to the flow of electricity in copper wires. Henry solved the problem by developing the electric relay (similar to a solenoid) that uses a small coil as an electromagnetic switch. This turns large amounts of electric current on and off, thus making unnecessary the circuit's continuous connection. This relay enabled electricity to be sent over long stretches of wires at intervals, and thus the success of the national system of telegraph communication. The problems related to the early electromagnetic telegraph were money and support for implementation, not the scientific problems. Joseph Henry was so admired in the United States that in 1846 he was named the first secretary of the new Smithsonian Institution located in Washington, D.C.

See also Ampère; Faraday; Tesla

HERSCHEL'S STELLAR THEORIES AND DISCOVERIES: Astronomy: *William Herschel* 1738–1822) and *Caroline Lucretia Herschel* (1750–1848). England.

Herschel's theory of the sun's movement: *The sun (thus the entire solar system) is moving in the direction of the constellation of Hercules.*

Although he was not able to calculate the sun's speed of movement, William Herschel based his theory on observations to determine the direction of movement.

Herschel's theory for the structure of galaxies: *Based on his observations while using a telescope of his own design, William Herschel was the first to explain the structure of galaxies. He theorized that the Milky Way has more stars in its center and fewer toward its celestial poles. He also proposed that the Milky Way and many other galaxies are shaped like a flat, circular "grindstone."*

William Herschel is credited with the discovery of infrared radiation by passing a beam of sunlight through a prism and then placing a thermometer at the end of the spectrum just beyond the visible deep red end of the light spectrum.

Caroline Herschel, the sister of William Herschel, made a number of contributions to the field of astronomy in her own right. Both were born in Germany, but in 1757 during the Seven Years War, William moved to England where he made a living as a music teacher and performer. In 1772 Caroline joined her brother in Bath, England, where he became an organist at the Octagon Chapel and she became a successful soprano singer. During this time William became interested in astronomy and began making telescopes to observe the heavens. Caroline joined him in his observation. While using a large reflector telescope, they soon discovered a celestial phenomenon in 1781 that William believed was a comet. In the meantime, their work impressed King George III of England who gave William a pension in 1782 to serve as his astronomer and commissioned him to build a large reflector telescope. Caroline then abandoned her singing career to become William's full-time assistant. Other astronomers soon identified what William and Caroline thought was a comet as a new planet. William wanted to name it "*Georgium Sidus*" meaning George's Star, after his patron George III, but another astronomer suggested that the name "Uranus" be given the new planet.

An interesting mnemonic device for remembering the nine planets is ''My Very Educated Mother Just Served Us Nine Pizzas.'' A problem with this sequence is that in August 2006 at a meeting of the International Astronomical Union in Prague, Czechoslovakia, and after years of debate, astronomers who had remained for the last day of the conference voted to ''downsize'' Pluto to a minor planet that no longer fits their classification as a true planet.

The controversy: Only 424 astronomers participated in the vote, representing less than 5% of the world's astronomers. As a result, there will be three main categories of objects in the solar system, as follows: 1) *planets,* the remaining eight (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune); 2) *dwarf planets,* Pluto and any other round object that ''has not cleared the neighborhood around it, and is not a satellite''; and 3) *small solar system bodies,* that orbit the sun.

Many astronomers expect the decision to be overturned sometime in the future, and to that end, are circulating a petition in support of a reversal.

Much of their work extended and improved upon the observations of other astronomers using this improved telescope. Caroline recorded William's observations as they extended the one hundred nebulae listed in the catalog compiled by the French astronomer Charles Messier (1730–1817). The list soon expanded to over two thousand nebulae that the Herschels discovered. As William became involved in other activities, Caroline used their telescopes to do more and more observations on her own. In 1783 she discovered her first new object, a cluster, now known as NGC2360. Later that year she discovered her second object, a galaxy known as NGC205. Other astronomers as well as King George III who recognized Caroline's discoveries paid her as the assistant to her brother for her contributions to astronomy. In addition to discovering many galaxies, Caroline had discovered eight comets by 1797. She became a well-known observational astronomer in her own right. Before her death she prepared a catalog of twenty-five hundred nebulae. Although it was never published, she did receive the Gold Medal from the Royal Astronomical Society in recognition of her contributions to the field.

In 1887 William discovered two satellites of Uranus named Titania and Oberon. Soon after, he found two satellites of Saturn (Mimas and Enceladus). He designed and built a new type of telescope that was forty feet long with a twelve-meter mirror. It eliminated the need for a secondary mirror that was installed in Newtonian-style scopes. This improved the viewing resolution but required agile observers, as they had to climb up the forty-foot scope.

See also Bode

HERTZSPRUNG'S THEORY OF STAR LUMINOSITY: Astronomy: *Ejnar Hertzsprung* (1873–1967), Denmark.

> *The luminosity of stars decreases as their color changes from white to yellow to red due to a decrease in the star's temperature.*

Previous to Ejnar Hertzsprung's theory, a star's distance from Earth was determined by the Doppler effect, the result of sound or light waves lengthening (lower

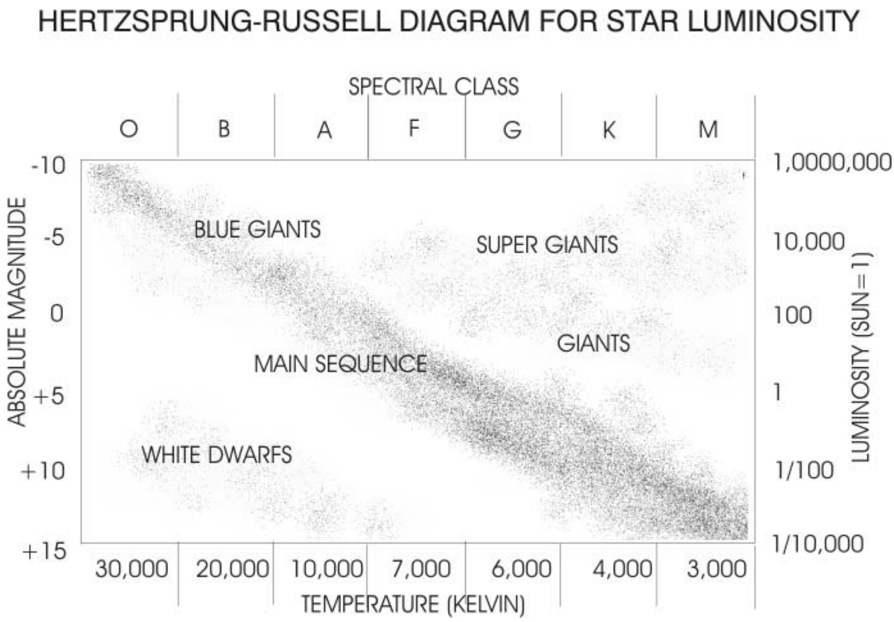


Figure H6. The Hertzsprung–Russell diagram depicting the color and magnitude of stars. It indicates how stars vary according to size, temperature, and brightness. Our sun is an average size star located about in the middle of the main sequence.

frequencies) as the object producing the sound or light waves moves away from the observer. Vice versa, the waves shorten and become higher in frequency as the object producing the waves approaches and moves closer to an observer. Hertzsprung improved this technique for determining the distance of stars by using photographic spectroscopy to measure the inherent brightness or luminosity of stars. He determined there were two main classes of stars: the supergiant stars that were very bright and the much more common and fainter stars referred to as the main *sequence type stars*. Henry Russell, who charted the stars according to Hertzsprung's classification, confirmed Hertzsprung's theory in 1913, and both are credited with developing the star diagram. The Hertzsprung–Russell diagram (referred to as the H-R diagram) arranged stars on the x-axis according to a classification using temperature and color, and also on the y-axis according to their magnitudes and luminosities (*see* Figure H6).

The diagram reveals several clusters or groupings of stars:

1. The most massive types of stars are the *supergiants*—the largest and brightest stars that show a large spread in intrinsic brightness. Although a few supergiants are larger than the orbits of Jupiter, most of them are smaller. All supergiants are comparatively rare and short-lived, but even at their great distance from Earth, many are redder than the main sequence of stars, but larger. They can be viewed easily because of their great brightness. Many supergiants are binary star systems (two stars circling each other as they are caught in each other's gravitational systems). Binary stars are somewhat easier to locate due to their brightness.

2. The *giants* are not quite as large and bright as the supergiants. They are yellow to orange to red and about one hundred times brighter than the sun with radii ten to twenty times that of the sun. Several examples of giants are Capella, Arcturus, and Aldebaran.
3. The *main sequence of stars*, ranging from very large dim stars to small, bright stars. The sun is near the middle of the main sequence.
4. The comparatively small *white dwarfs* are about 10 magnitudes less than the main sequence of stars in the diagram and are in their last stages of evolution.

The large bright and cooler stars are found in the upper right of the diagram, while the smaller white dwarfs, which are somewhat dimmer and hotter, are located in the lower left of the x-y coordinates of the diagram. The sun is found among a group of small stars known as red dwarfs, which are located near the middle of the main sequence. It is somewhat more brilliant than its neighbors.

Hertzsprung's work and the H-R diagram led to a better method for determining the distance of stars and galaxies from Earth, as well as aiding in the study of the evolution of stars. The H-R diagrams are also called "color-magnitude" diagrams because the spectra used to place stars into categories is dependent on a star's color which is determined by its temperature.

See also Hewish; Russell

HERTZ'S THEORY FOR ELECTROMAGNETIC WAVES: Physics: *Heinrich Rudolf Hertz* (157–1894), Germany.

Electromagnetic waves, produced by electric sparks, behave the same as light waves.

Heinrich Hertz expanded the electromagnetic theories of James Clerk Maxwell and Hermann Helmholtz by erecting an apparatus consisting of a metal rod with a small gap cut in the center to detect different wavelengths of the electromagnetic spectrum. When electricity was sent through the rod, a rapidly vibrating spark was produced at the gap, generating high frequencies in the rod. Not only was Hertz able to detect these high frequencies (electromagnetic waves), but he also determined that these electromagnetic waves would reflect and refract off surfaces just the same as light waves. More important, he discovered that electricity is transmitted as electromagnetic waves that travel at the same speed as light. He also showed the wavelengths of electricity were quite a bit longer than gamma radiation or even light rays. They were named *Hertzian waves*. Today we know this range of electromagnetic waves with very long wavelengths as radio waves. They have wavelengths not only much longer than light waves, but longer than most other waves of the electromagnetic spectrum. Hertz's work not only confirmed Maxwell's electromagnetic spectrum theory, but also paved the way for radio communications (*see* Figure M4 under Maxwell). Hertz experimental work more-or-less established the field of electrodynamics. He also published two papers that analyzed and confirmed Maxwell's theory in 1890. His theory and experimentation (based on the theories and experiments of Nikola Tesla) led to the development of wireless communication proposed by Tesla. Their work led to wireless telegraph, radio, television, cell phones, etc. The SI metric unit for expressing frequency is named for Heinrich Hertz. It is known as the Hz.

The terms ''wavelength'' and ''frequency'' are often confused—the *velocity* of a wave, its *frequency*, and its *length* are all interrelated components of waves. Waves, some very short, others very long, can be formed in all kinds of substances in any of the three states of matter. Waves occur in water and other liquids, gases, earthquakes, and electromagnetism (light, radio, X-ray, etc.). The frequency of a particular wave is given in terms of the number of wave crests that pass a given point in a second, whereas the wavelength is the distance between the successive crests of each wave passing a point. This wavelength is directly proportional to the wave's velocity but inversely proportional to its frequency (i.e., how many crests of the wave pass a given point over time). This can be expressed in the following equation: $V = \lambda f$, where V is the velocity of the wave, f is its frequency, and λ (lambda) is its wavelength. If two of these facts concerning a wave are known, the unknown fact can be calculated, that is, to determine the wavelength, use the variation of the equation: $\lambda = V/f$ (by dividing the velocity of the wave by its frequency will give you the unknown wavelength).

It is reported that when experimenting with various frequencies Hertz also accidentally detected the photoelectric effect. Others already knew this effect, but Hertz used ultraviolet light (wavelengths just shorter than visible light) to "knock" out electrons (photons) from the surface of particular types of metal plates.

See also Curie (Pierre); Helmholtz; Maxwell; Tesla

HESS' SEA-FLOOR SPREADING HYPOTHESIS: Geology: *Harry Hammond Hess* (1906–1969), United States.

The sea floor ''split'' near the middle of the Atlantic Ocean provides an opening for deeper magma to protrude, thus renewing and spreading the ocean floor under landmasses, which eventually separated the continents.

At one time Earth's entire land mass was connected. Over millions of years, this mass separated to become distinct continents. How this occurred has perplexed geologists because it did not seem possible that landmasses could pass over layers of solid rock. Hess's hypothesis provides a possible answer. Hess based his hypothesis on evidence that fossils found in the "newer" ocean beds are much younger than those found on continental landmasses. As the ocean floor spread out, it approached the landmasses and dipped under the continents, while at the same time forming a ridge at the origin of this expansion (*see* Figure H7).

This movement of ocean floors resulted in the development of rifts or breaks near the center of the Atlantic and Pacific Ocean beds as the seafloor was "pulled" apart along a rather narrow crack down a central ridge in the ocean floor over seventy-five thousand miles long. This produced weak spots where the magma (molten rock) protrudes through what is known as the midocean ridge, which is a deep canyon running down the middle of the North and South Atlantic Oceans, across to the Pacific and Indian Oceans to form the center of what is known as the Great Global Rift. As volcanic material rose up from Earth's mantle and out of the great fissure, it constantly fills up the crack, creates new ocean floors, and spreads out toward the continents. This spreading of the sea floor eventually was forced underneath land masses and is responsible for the North and South American continents moving farther apart and westward, while moving Europe and Asia eastward. The continents did not actually drift or float but were rather fixed to plates that were forced apart and, in some places, forced together.

Hess' research and hypothesis led to the science of plate tectonics, from the Greek work *tektonikos*, meaning "builder." Plate tectonics, an important geological theory, is

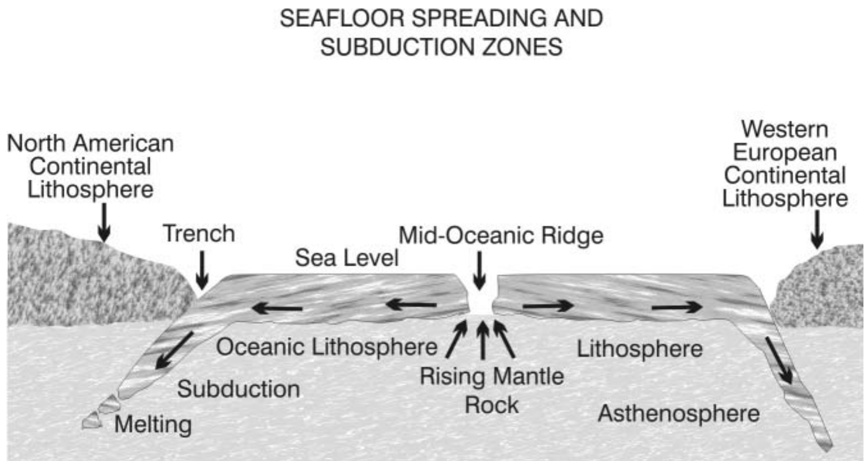


Figure H7. The mid-oceanic rift is a deep canyon running down the ocean sea floor as it spreads both east and west

as important to geologists as evolution is to biologists. In essence, it states that worldwide, there are six large plates and some smaller ones that were moved by the spreading of the oceans' floors. These ocean floors and plates move apart about two inches each year as new magma rises into the midocean rifts. Earthquakes and volcanoes are in evidence where some of the major plates clash, such as on the West Coast of the United States and South America and in the plates bordering Japan and much of the Pacific Ocean. This movement produced, and still produces, mountains and island chains. Hess' hypothesis was later confirmed by studies of the magnetic properties of the new magma material compared to the older magnetic properties of the ocean floor.

See also Suess; Wegener

HESS' THEORY FOR THE IONIZATION OF GASES: Physics: *Victor Francis Hess* (1883–1964), United States. Victor Hess shared the 1936 Nobel Prize for Physics with Carl Anderson.

As altitude increases, so does the level of ionizing radiation that affects gases.

Victor Hess noted that, over time, **electroscopes** that had received a charge when exposed to air lost their charge. He theorized that the upper atmosphere emitted some kind of radiation. First, in 1910 he timed the discharge of the leaves in his electroscope at different levels as he ascended to the top of the Eiffel Tower in France that is about three hundred meters high. Not much difference was noted. Next he tried his experiment in a balloon. At low altitudes, the rate of discharge was much the same. But as he increased the altitude from several thousand feet to over sixteen thousand feet, a much more rapid discharge of the electroscope became evident. He made ten balloon trips, five at night, over the period from 1911 to 1913. His original theory proved

Victor Hess was born in Austria where his father was a forester. He attended the local gymnasium and later in 1901 entered the University of Graz where in 1906 he received his PhD in physics. He held several teaching positions before and after his famous "cosmic" ray experiments for which he shared the 1936 Nobel Prize with Carl D. Anderson who discovered the positron. He moved to United States when he was offered a professorship at Fordham University in New York City. He became a citizen in 1944. After the atom (nuclear) bomb was dropped, he studied atmospheric radioactive fallout from the top floors of the Empire State Building in New York. Later he studied radiation levels emitted by granite rock deep in the subway station at 190th Street. In 1948 Hess and another investigator developed a method of detecting and measuring minute amounts of radium in human bodies. Following World War II this proved to be an important means of detecting radiation poisoning before it became life threatening. He could also measure any radiation in the breath of people who worked around radioactive materials. He determined that different people have different levels of tolerance to radiation. However, the effects of exposure to radiation by the human body are cumulative and may take many years before radiation sickness becomes evident. Victor Hess opposed the use of all nuclear weapons and their testing, even underground.

correct. There was some form of radiation coming from outside Earth's atmosphere that was absorbed by the more dense gases at low altitudes but was not impeded at higher altitudes. He concluded that very strong radiation entered Earth's atmosphere far from Earth. At first he believed the ionizing radiation came from the sun. During a total eclipse of the sun, he noticed that the rate of discharge at great heights was always the same as when there was no eclipse, and that the level of radiation was the same during the daylight hours as it was at night. Hess then theorized that the radiation came from outer space. The scientific community remained unconvinced. At the time, most people continued to believe this form of radiation came from either the sun or some unexplained phenomenon on Earth. His work led to the discovery of cosmic rays by Robert Millikan a few years later.

See also Millikan

HEWISH'S THEORY OF PULSARS: Astronomy: *Antony Hewish* (1924–), England. Antony Hewish shared the 1974 Nobel Prize for Physics with Martin Ryle.

Pulsars are rotating neutron stars that send out electromagnetic signals with great precision that can be detected on Earth.

Antony Hewish was born in Cornwall, England, and entered Cambridge University in 1942. However, in 1944 he was soon involved with war-related research with several government agencies. When he returned to Cambridge in 1946, Hewish joined the research team at the Cavendish Laboratory headed by the British radio-astronomer Sir Martin Ryle. He continued teaching along with his research on radio astronomy. Jocelyn Bell Burnell, his graduate research assistant, was assigned the job of using the main telescope and then analyzing the results on charts produced by the telescope. She noticed variability in the scintillation of one of the pulsating radio signals from a small star in the Milky Way galaxy. She correctly figured that the rate of pulsation was much too fast to be produced by a regular quasar. At that time, Bell Burnell had adequate training to realize that this was evidence of a new type of radio star that was later referred to as a pulsar. When Hewish and Ryle received the 1974 Nobel Prize, Jocelyn Bell Burnell was excluded. Both men were extremely upset about this exclusion, as were many other astronomers, because it was she who had actually discovered the data that led to the identification of pulsars (Jocelyn Bell Burnell went on to a distinguished career in astrophysics before retiring from the University of Bath, England, in 2004).

The word "pulsar" is the abbreviation for "pulsating radio star." Hewish recognized the importance of Bell Burnell's discovery and named it PSR 1919+21. Later, it was discovered that pulsars act as "lighthouses" because they not only rapidly emit radio pulses, but also pulses of light and X-rays. There are three classes of pulsars: 1) pulsars whose rotations are powered by the internal energy derived from that rotation; 2) X-ray pulsars that emit X-rays that can be detected on Earth that rotate from potential gravitational energy; and 3) magnetic pulsars whose energy of rotation is derived by the decay of strong magnetic forces as internal heat dissipates toward their poles. Although pulsars are very small in comparison to other bodies in the universe (only about ten to fifteen miles in diameter), their mass is several times the mass of our sun. Their speed and period of rotation also varies.

Several astronomers, including the late American astronomer Thomas Gold, hypothesized that pulsars are rapidly rotating neutron stars. Due to the mysterious nature of pulsars, some astronomers considered that they might be a form of communication from extraterrestrials (ET). One wag even named their pulsar LGM-1 for "little green men." At one time several astronomers in England and the United States seriously considered this possibility based on the fact that the signals were so regular. Today, even though much more still needs to be uncovered about pulsars, astronomers no longer consider the possibility of ET signals a viable explanation.

See also Gold; Hertzsprung

HIGGINS' LAW OF DEFINITE COMPOSITION: Chemistry: *William Higgins* (1763–1825), Ireland.

> *When atoms of specific elements combine to form molecules of a compound, they do so in a ratio of small, whole numbers.*

William Higgins claimed to be the first to conceive that simple and multiple compounds composed of the same elements are combined in a ratio of small, whole numbers. Despite having no experimental evidence for his proposition, he based his law of definite or constant composition on the concept that for any molecular compound that contains atoms of the same element, these atoms combine in the same fixed and constant proportions (ratio) by weight. Higgins' theory was speculative. Shortly after, John Dalton expanded Higgins' atomic theory by adding the statement that atoms are neither created nor destroyed in chemical reactions and that the molecules of compounds are composed of one or more atoms of the elements forming the compound. Further, these elements always combine to form compounds (molecules) in ratios of small, whole numbers of the atoms of the constituent elements. Higgins' law is best understood when considering molecules of oxygen: O_2 (oxygen) and O_3 (ozone). Dalton's contribution to the law is better understood when comparing the five oxides of nitrogen—for example, for NO, NO_2, N_2O, N_2O_3, and N_2O_5, each compound molecule has a different ratio of small, whole numbers by weight combining the two elements, nitrogen and oxygen. Higgins' law of definite composition relates to the ratio of the small, whole numbers of atoms of the same element combining to form a molecule (e.g., $O + O + O_2$), whereas Dalton's law of multiple proportions relates to the ratio, in small, whole numbers, of the weights (atomic mass) of the atoms of *different* elements combining to form a compound (e.g., $2H + O = H_2O$). Today, most scientists consider Higgins and Dalton among the founders of modern chemistry.

See also Atomism; Dalton

HIGGS' FIELD AND BOSON THEORIES: Physics: *Peter Ware Higgs* (1929–), England.

At very low temperatures, the symmetry of the electromagnetic force breaks down, producing massive particles (Higgs bosons) from formerly massless particles.

Peter Higgs endeavored to unify electromagnetic waves and the "weak" force into a single "electroweak theory" (*see* Figure G11 under Glashow). He and other physicists observed that at high temperatures, electromagnetic photons and weak force W and Z bosons were indistinguishable from each other. Both seemed massless. Bosons are elementary particles that obey a particular type of statistical mathematics. Some examples are photons, pi mesons, and particles with whole number "spin," as well as nuclei of atoms composed of an even number of particles. Higgs subjected these particles to extremely low temperatures, at which point their symmetry no longer existed, and therefore photons could be distinguished from the W and Z bosons. A mathematical expression of this phenomenon became known as the *Higgs field*, which attributed the weightless bosons with mass. This formerly weightless boson, which now had theoretical mass, became known as the *Higgs boson*. An elementary particle, the Higgs boson, derived from the combined theory of electromagnetic and weak interactions, has not yet been detected. It is more massive and has a much higher level of electron volts, meaning that one of the newer, high-energy superconducting supercollider particle accelerators will be needed for its detection.

Scientists are still not sure if the Higgs boson really exists with a mass less than the Z particle. However, they hope to discover it and then fit the boson into the scheme for the "electroweak theory." For over ten years they have been using the Large Electron Positron (LEP) collider located in Geneva, Switzerland, that accelerates electrons and positrons to very high energies and guides them into collisions. Since then, the Large Hadron Collider (LHC) at CERN has been placed into position to continue research on the Higgs boson. Also the Fermi National Accelerator Laboratory in Batavia, Illinois, was used to smash particles together at very high speeds that produce energies high enough to convert the particles into smaller bits of matter. Hopefully, one form of these small bits of matter will be a Higgs boson. Because it lasts for only a small fraction of a second and then decays into something else, scientists look for what it might decay into. One of the purposes of the Superconducting Super Collider (SSC) that was being constructed in Texas in 1991 was to discover the Higgs boson. After the large underground circular accelerator was started, Congress canceled the funds for this project in 1993. The abandonment of the SSC devastated the United States' worldwide position and lead in the field of particle physics.

HODGKIN'S THEORY OF ORGANIC MOLECULAR STRUCTURE: Chemistry: *Dorothy Crowfoot Hodgkin* (1910–1994), England. Dorothy Hodgkin was awarded the 1964 Nobel Prize for Chemistry.

The structure of complex organic molecules can be determined by use of X-ray analysis.

The use of X-ray diffraction to study subatomic particles too small to be seen by optical microscopes was developed by Max Von Laue. His concept stated that X-rays were electromagnetic waves similar to light waves but with much shorter wavelengths that could "see" particles invisible to ordinary optical microscopes because the submicroscopic particles were smaller than the length of a light wave. He developed a technique for passing X-rays through a crystal, forming a diffraction pattern of the crystal's structure. Dorothy Hodgkin perfected the technique to produce diffraction patterns that revealed the structures of comparatively large organic molecules. Working with her teacher, John Desmond (J.D.) Bernal (1901–1971), she made the first X-ray photographs of the large protein molecule pepsin. Hodgkin then produced a three-dimensional photograph of penicillin, which aided in understanding its molecular composition. Later Hodgkin used X-ray diffraction to determine the structure of the vitamin B_{12} molecule, which is constructed of over ninety atoms. This enabled the vitamin to be produced in quantities adequate for the virtual elimination of pernicious anemia. She received the 1964 Nobel Prize for Chemistry for her work with B_{12}. Subsequently, with the aid of computers, she successfully determined the structure of the insulin molecule that has over eight hundred atoms.

HOFFMANN'S THEORY OF ORBITAL SYMMETRY: Chemistry: *Roald Hoffmann* (1937–), United States. Roald Hoffmann shared the 1981 Nobel Prize for Chemistry with Kenichi Fukui.

> *Using quantum mechanics, it is possible to predict and explain the symmetry of chemical reactions.*

Roald Hoffmann and Robert Burns Woodward collaborated in the development of an orbital molecular theory, now referred to as the *Woodward–Hoffman rule*. Woodward is known for his work on synthesizing natural substances of very complex structures, whereas Hoffman was more concerned with how chemical bonds were formed and broken during chemical and cyclic reactions. Hoffmann advanced theories related to the electronic (orbital) structure of stable and unstable inorganic and organic molecules. His work on the transition states of organic reactions led to the concept of bonding and symmetry used for the analysis of complex reactions. The Woodward–Hoffmann rule outlined the **stoichiometry** taken during the total summing up of the many steps required to complete complex chemical reactions. This rule enables organic chemists to understand the structure of complex natural substances and synthesize them from simpler chemicals, resulting in chemical synthesizing (artificial production) in the laboratory of many substances found only in nature. A few examples are cholesterol, lysergic acid, reserpine, some antibiotics, and, most important, chlorophyll.

See also Woodward

HOOKE'S LAWS, THEORIES, AND IDEAS: Physics: *Robert Hooke* (1635–1703), England.

Hooke's law of elasticity: *The change in size of a material under strain is directly proportional to the amount of stress producing the strain.*

Robert Hooke was the first to apply mathematics to the concept of elasticity and relate this concept to the actions of springs. In essence, his law states that the distance over which a spring is stretched varies directly with its tension, as long as the spring does not exceed its limits of elasticity—that is, the strain is proportional to the stress. In other words, the more a spring is stretched, the greater becomes its internal tension. Once this was understood, springs could be designed for vehicles to provide smoother ground transportation. Hooke's law of elasticity applies to all kinds of situations and materials, from bouncing balls to the use of an elastic rod or fiber as a torsion balance. Hooke was the first to relate the simple harmonic motion concept for pendulums to the vibrations of micro "hair" springs used in the balance wheels of smaller watches. Hooke also improved the escapement movement in clocks first conceived by the ancient Chinese, by devising a method of cutting small but accurate cogs and gears. This special cog, called the *grasshopper escapement*, enabled pendulum-driving grandfather-style clocks and the pocket watch to be constructed as very accurate timepieces for their time in history (*See also* Huygens).

Hooke's cell theory: *All plants are composed of cells surrounded by a defined cell wall.*

Hooke's concept of cells resulted from the construction and use of his practical compound microscope. He observed and drew elaborate diagrams of objects such as feathers, insects, and fossils. His most famous microscopic observation focused on the walls of individual cells in a thin slice of cork, which is nonliving plant tissue. Hooke based his concept of and name for "cell" on the tiny monks' rooms in monasteries, called cells. Other biologists then examined living plant cells, all of which had well-defined cell walls, whereas the walls of animal cells were shaped like irregular membranes. Hooke's cell concept led to the development of the modern cell theory, which states that all living plants are composed of cells derived from other cells, as well as the extension of the plant cell theory to animal cells (*See also* Schleiden; Schwann).

Hooke's theory of sound and light waves: *Sound is transmitted by simple harmonic motion of elastic air particles, thus, light must also be transmitted by a similar wave motion.*

Robert Hooke applied his law of elasticity to air particles that are compressed (squeezed tighter together) and rarefied (spread farther apart) as these particles proceed from the source of the sound to a person's ears (the Doppler effect). He concluded that light, both colored and white, was transmitted in a similar wavelike motion through air. (Actually, light waves are not exactly similar to compression-rarefaction-type sound waves. Light has the dual properties of both particles and electromagnetic radiation or waves.) Hooke also extended his law of elasticity to form his own theory of gravity, which he based on mathematics related to the harmonics of planetary motion (a backward approach to the law of gravity as proposed by Sir Isaac Newton). In addition, Hooke claimed that he, not Newton, first conceived the concept that gravity obeyed the universal concept of the inverse square law. A disagreement developed in which Newton disputed Hooke's theories and claims.

See also Newton; Stark

HOYLE'S THEORIES OF THE UNIVERSE: Astronomy: *Sir Fred Hoyle* (1915–2001), England.

Hoyle's steady-state theory: *The universe did not originate from the big bang, but rather exists in a steady state.*

Sir Fred Hoyle disagreed with the big bang theory proposed by George Gamow and other cosmologists. The big bang theory, a term that Hoyle originated, some say disparagingly, states that the universe started as an incredibly dense point or tiny ball that contained all the matter and energy now existing in the universe. Steven Weinberg of the University of Texas and others assert that the beginning occurred as a singularity event where, in the first three minutes of creation, a small but rapidly expanding universe was so hot and dense that only subatomic elementary particles and energy existed. This was followed by the production of hydrogen and later helium as stars and galaxies. Other matter rapidly evolved and expanded and continues to expand today. As the stars evolved, they produced the heavier elements now found on the planets. Hoyle, a respected astronomer, rejected this theory of an expanding universe and proposed a continual creation of atoms and other matter to the extent that for a volume in space the size of a house (about thirty thousand to fifty thousand cubic feet), only one atom is created each year. He further claimed this constant creation of matter explains the formation of new galaxies. Hoyle believed the universe is closed and thus exists as a steady-state universe. Cosmological research, observational evidence, and mathematics over the past forty years or so seem to discredit the concept of a closed steady-state universe, but the debate continues (*See also* Weinberg).

Hoyle's theory for the origin of the solar system: *The original sun was a binary star, one of which separated and exploded. Over time, the force of gravity coalesced the exploded matter of the second star that, due to mutual gravity, formed the planets, comets, asteroids, and so forth, of the present solar system.*

Fred Hoyle made a number of contributions to astronomy and cosmology and provided a great deal of mathematical support for various theories. His theory for the formation of the planets in our solar system states that our sun was, at one time, one twin of a two-star (binary) system. One star exploded, but the gravitational attraction of the remaining star (our sun) maintained the pieces of the exploded star in orbits around our sun. In time, these chunks of matter attracted each other and piled up into great masses that became the existing planets, still revolving around our star as they are captured by the gravity of its great mass. This theory is considered a viable account for the formation of the planets as well as comets, asteroids, and meteors.

Hoyle's theory for the formation of the elements: *Hydrogen is "fused" into helium inside stars, which also combined to form heavier elements.*

One of Fred Hoyle's most important theories explains how hydrogen is converted into helium inside the sun by the reaction of atomic (nuclear) fusion, which is the same reaction that occurs when a nuclear fusion (hydrogen) bomb explodes. In addition to this reaction that creates helium plus all the energy output of the sun, Hoyle theorized that a similar process occurred inside the sun to form the heavier elements. One example is the formation of a carbon atom (atomic number 6, mass number 12) from three atoms of helium (atomic number 2, mass number 4): ${}_{2}\text{He-}4 + {}_{2}\text{He-}4 + {}_{2}\text{He-}4 \rightarrow {}_{6}\text{C-}12$. A similar reaction formed the lighter elements as well as the heavier elements with which we are familiar on Earth. This relates to Hoyle's theory for the formation of the planets of the solar system when the chunks of the exploded twin of our sun agglomerated. These chunks of matter contained all of the known elements at the time the planets were formed.

Hoyle's disclaimer for the reptile/bird theory: *Reptiles did not evolve into birds.*

Hoyle believed there were interstellar grains similar to bacteria that brought life to Earth from outer space. Svante August Arrhenius first proposed this theory, called *panspermia*. However, the theory is no longer valid because it has been demonstrated that cosmic radiation would kill extraterrestrial life forms of this type. This idea not only influenced Hoyle's concept for the origin of life, but also affected his ideas related to the evolution of species and the use of fossils to explain evolution. He was unconvinced that fossils represented extinct species. Hoyle became involved in a dispute with a geologist over a type of fossil claimed to represent a species between a dinosaur-type reptile and a bird (Archaeopteryx). Hoyle claimed it was a fake because he insisted the feathers had been glued onto a reptile skeleton to make it seem part bird. The British Museum conducted many tests and found no evidence of glue or of any other deception. Recent studies of DNA, bone structure, and other anatomical comparison have established an evolutionary relationship between birds and reptiles.

See also Arrhenius; Redi

HUBBLE'S LAW AND CONSTANT: Astronomy: *Edwin Hubble* (1889–1953), United States.

Hubble's law: *The velocity of a galaxy that is receding from us is proportional to its distance from Earth.*

Even before Edwin Hubble could utilize the one-hundred-inch Mount Wilson telescope in California, he studied faint "clouds" of gas and dust that appeared as fuzzy images. He considered some of these areas as originating from our Milky Way galaxy. Other images seemed to originate from more distant areas of space, which were called *nebulae*. Once he was able to use a powerful telescope, he identified these more distant dense "clouds" of luminous gases as clusters composed of many millions, perhaps billions, of stars that are billions of light-years from Earth. He identified two types of these nebulae galaxies—one as spiral, the other as elliptical. He further classified elliptical galaxies as to their shapes approximating a circle. Although not all observed phenomena in deep space fall into these two classifications, Hubble's descriptions are still the basis for galactic classification. He also discovered several cepheids, which are stars that vary in their brightness (period-luminosity). These bright variable stars provide a means for measuring the distance of galaxies relatively near us—about one million light-years distant. From these data he proposed Hubble's law, v = Hd, where v is the recessional velocity of the galaxy, d is its distance from us, and H is known as Hubble's constant. To develop this law, Hubble measured the distance of about a dozen and a half galaxies of several different classifications and related their receding velocities to the degree of red shifts in their light. He then devised the Hubble diagram where the x-axis is the distance and the y-axis is the amount of red shift of the wavelength of the galaxies' light (*see* Figure H8).

Hubble's constant: *The original value of the Hubble constant (H) was 150 km/sec/ 1,000,000 light-years.*

Edwin Hubble overestimated the value for his constant by a factor of eight to ten. It has since been corrected as H = 15-30 km per second per Mpc. The symbol H for the constant is sometimes written as H_0, the range of fifteen to thirty kilometers is still not an exact known distance, and *Mpc* is a *megaparsec*, which is equal to 10^6 parsecs. The parsec is a unit used in astronomy to measure very large stellar distances. It is equal to 3.856×10^{13} km, or 3.2615 light-years. Hubble's constant is important for two reasons. First, it provides the factor necessary for relating the red shift from the light of stars to their distances, thus providing a means of calculating the observable size of the universe. And, second, the reciprocal of Hubble's constant provides a means to determine the age of the universe. It is possible to calculate how long it would take galaxies to backtrack (contract) their now-expanding movements to their state at the origin of the

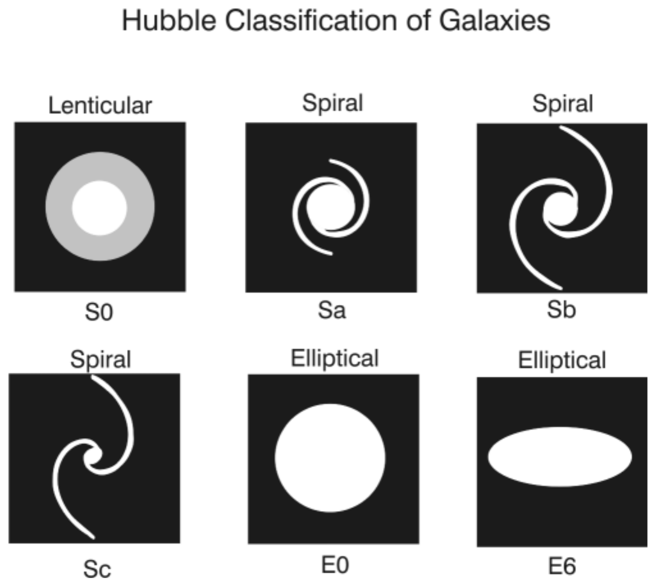


Figure H8. The apparent shapes of different galaxies are partly the angle of the viewing telescope.

universe. The current figure for the age of the universe, as calculated by the reciprocal of Hubble's constant, is between ten and twenty billion years, with a reasonable estimate of fourteen to fifteen billion years since the time of the big bang.

See also Gamow; Hale; Hertzsprung; Hoyle

HÜCKEL'S MO THEORY OR RULE AND THE DEBYE–HÜCKEL THEORY:

Chemistry: *Erich Armand Arthur Joseph Hückel* (1896–1980), Germany.

Hückel's molecular orbital theory: *Aromatic cyclic compounds similar to benzene are planar compounds that have 4n + 2 π-electrons (when* n *equals either a 0 or just a small whole number, it will determine how many aromatic rings a particular compound will have).*

Hückel developed his MO rule in 1930 to explain π-electron systems that limited rotation of ring structures similar to benzene-like organic ring compounds that contain double C bonds (C=C). The Hückel 4n+2 rule could be used to determine if ring molecules of aromatic compounds such as benzene are composed of C=C bonds (*See also* Kekule;Van't Hoff).

Hückel was born near Berlin, Germany, and was educated at the University of Göttingen. After receiving his doctorate in experimental physics in 1921, he became an assistant to the Dutch physicist, Peter Debye, at the Federal Institute of Technology in Zürich, Switzerland. While in Zürich, together they developed the Debye–Hückel theory for electrolytic solutions. However, Hückel's work was mostly ignored until his death, primarily because he had a difficult time communicating his ideas to other scientists. Although he never won a Nobel Prize, other scientists in his field have acknowledged his contributions to the field of chemistry.

Debye–Hückel theory of electrolyte solutions: *In concentrated solutions, as well as dilute solutions, ions of one charge will attract other ions of opposite charges.*

This theory assumes that strong electrolytes are fully dissociated into ions while in a solution state. This theory is used to calculate the properties of electrical conductivity for dilute solutions. This theory also accounts for the conductivity of ionic solutions by considering the forces between the ions within the solutions. Their theory takes into consideration the interactions of ions in a solution that explained the differences between dilute solutions of electrolytes and what is referred to as an ideal solution.

HUGGINS' THEORY OF SPECTROSOPIC ASTRONOMY: Astronomy: *Sir William Huggins* (1824–1910), England.

> *The chemical composition of stars and nebulae can be determined by the use of a spectroscope.*

After receiving an early education at home, William Huggins was sent to a private school for further training. After graduating from the City of London School, he tried involving himself with his father's silk business but soon gave that up to devote himself to science. He became familiar with the work of Robert Bunsen, who invented the gas Bunsen burner, and Gustav Kirchhoff who, along with Bunsen, invented an instrument that used an optical prism device. They called it a spectroscope because it could be used to separate visible light emitted from chemicals that were vaporized by Bunsen's gas burner that produced a high-temperature nonluminous flame. Gas produced from the burning of any substance produces a unique pattern of spectral lines that can be distinguished when viewed through the spectroscope. The unique signature spectrum for each element is created by its atomic structure that is different for each specific element. As an atom's electrons jump between different orbitals (energy levels), electromagnetic energy in the form of light is generated. These "excited" electrons are what cause the unique spectrum of atoms of different chemical elements. Kirchhoff determined that the dark lines seen when viewing chemical substances were the same dark lines in the spectrum of light from the sun. From this data it was determined that the sun was composed of very hot gases.

Being familiar with this information, Huggins first examined the spectra of the stars. After acquiring a fine spectroscope, he examined the spectra of several chemicals found on Earth and then, in collaboration with

> Although he was considered an "amateur" astronomer, the discoveries by William Huggins had a great impact on the science of astronomy. He made use of the discovery of the red shift by Christian Doppler and Armand Fizeau that proved that light waves from a source receding from an observer were of a lower frequency and thus of a longer wavelength than were the frequencies and wavelengths of waves approaching the observer. This shift known as the Doppler effect applies to light waves as well as sound waves. Huggins made use of this discovery of the red shift of light from stars by viewing a lower frequency (thus longer wavelength) that produced light near the red end of the light electromagnetic spectrum, which meant that that source of light was receding from earth. Huggins examined the spectrum of the star Sirius and determined that it had a noticeable red shift and, more important, that the degree of shift was proportional to the star's velocity away from Earth which was about twenty-five miles per second. This was evidence that the universe is expanding as distant stars recede from Earth as well as from each other.

a professor of chemistry at King's College in London, Huggins began a life-long investigation of the spectra of the stars and nebulae. In 1863 Huggins published his first findings that described the spectra of stars indicating that they are composed of the same chemical elements as the elements found on Earth. Following this discovery he resolved the mystery of the composition of nebulae that looked like interstellar clouds of gas or particles (e.g., Orion), which astronomers were unable to distinguish as stars. When Huggins looked at several nebulae with his spectroscope, to his surprise he saw only a single bright line. This proved that a nebula was not a clump of many stars, but rather a mass of luminous gases. After observing the spectra of several dozen nebulae he determined that about a third of the nebulae were of the gaseous type. Huggins also examined the spectra of the tails of comets and discovered that this gaseous "tail" is composed mostly of hydrogen. He also determined that the temporary star, Nova Coronae, was composed of mostly hydrogen.

As Huggins became older and his eyesight deteriorated, he had difficulty viewing objects through his spectroscope. His wife Margaret Lindsay Murray (Lady Huggins) then assisted him in viewing and recording observations. Together they prepared an *Atlas of Representative Stellar Spectra* in 1899. This atlas represented spectra from lambda 4870 to lambda 3300 along with an interpretation of their spectra and a detailed discussion of the evolutionary order of the stars.

See also Bunsen; Doppler; Fraunhofer; Kirchhoff

HUYGENS' THEORIES OF LIGHT AND GRAVITY: Physics: *Christiaan Huygens* (1629–1695), Netherlands.

Huygens' wave theory of light: *A primary light wave front acts as a spherical surface that propagates secondary wavelets.*

Christiaan Huygens was the first to conceive that light was propagated as waves and could support his theory by experimental observations. During Huygens' lifetime, most scientists supported the particle theory of light. Huygens, however, demonstrated that when two intersecting beams of light were aimed at each other, they did not bounce off one another, as would be expected if they were composed of minute particles with mass (conservation of momentum). He further theorized that light would travel more slowly when refracted through a denser medium than air. This was in direct opposition to Sir Isaac Newton's concept that light would maintain its speed when refracted toward the normal angle of light's motion. A more detailed statement of Huygens' wave theory is: *At every point on the main spherical wave front, there are secondary wavelets that at some time in their propagation are associated with the primary wave front.* Both the wavelets and wave front advance from one point in space to the next with the same speed and frequency. Since Huygens' time, the wave theory has been refined, and the wave–particle duality is now generally accepted. Electromagnetic radiation (light) waves are now also considered as particles, called *photons*, as explained by the quantum theory for the photoelectric effect and diffraction.

Huygens' concept of gravity: *Gravity has a mechanical nature.*

Huygens disagreed with Newton's law of gravity, which was based on Newton's laws of motion as well as the concept of force at a distance. Huygens considered Newton's theory of gravity as lacking the means to explain mechanical principles based on Cartesian concepts. Huygens used the term "motion" to mean "momentum" and considered the center of gravity to extend outward in a straight line similar to centrifugal force.

He based his theory on mechanics, which states there is no loss or gain of "motion" following a collision between bodies (conservation of "motion" or momentum). He further developed a mathematical explanation for perfect elastic bodies. Huygens' emphasis on the mechanistic nature of gravity was in direct conflict with his wave theory of light, based on secondary wave fronts he considered as massless waves that would not obey mechanistic rules. Over time, Newton's concept of gravity was accepted but revised to conform to the new theories of relativity and quantum mechanics by Einstein and others. Today's theory of gravity is still based on the relationship of bodies' masses and distances separating them. There is a modern concept for the wave nature of gravity based on yet-to-be discovered wave particles called *gravitons* (*see also* Einstein; Newton).

Huygens' concept for using the oscillations of a pendulum for timekeeping: *Based on the mathematics of curved surfaces and centrifugal force, the motion of an oscillating simple pendulum should maintain periodic time.*

Needing a device for accurate timekeeping for his work in astronomy and relying on the concepts developed by Galileo, Huygens worked out the mathematics of the pendulum, enabling him to develop the first accurate practical clock (*see* Figure G2 under Galileo). Much like today's grandfather clocks with a weighted bob suspended at the end of a long rod, it made use of slowly dropping weights and a crude escapement cog to maintain the swing of the pendulum at regular intervals. Huygens also developed a method for grinding lenses that improved the resolution of telescopes. Along with his pendulum clock and telescopes, Huygens made several discoveries, one of which was to identify a separation in the rings of the planet Saturn, another was the discovery of one of Saturn's moons.

See also Galileo; Hooke; Newton

I

IDEAL GAS LAW: Chemistry: *Robert Boyle*, England; *Jacques-Alexandre-Cesar Charles* and *Joseph-Louis Gay-Lussac*, France. This entry is a combination of several laws, theories, and hypotheses developed by several scientists.

The ideal gas law may be expressed as PV = nRT, or PV/T = nR, where P = pressure, V = volume, T = temperature, n is the number of moles of gas in the system, and R is the gas constant equal to 8.314 joules.

The French physicist and inventor Guillaume Amontons (1663–1705) was the first to measure and state the relationship between the temperature of a gas and its volume. He accomplished this by using an improved air thermometer similar to one devised by Galileo (*see* Figure G3 under Galileo). Amontons demonstrated that the volume of a gas increased at a regular rate when heated, and, conversely, its volume decreased when the gas was cooled. He also concluded that this relationship applied to all gases. His work was undiscovered, and Robert Boyle was later credited with recognizing the relationship between the volume and pressure of a gas at a constant temperature.

The ideal gas law is also referred to as the *law of perfect gases* or the *generalized gas law*. It is a combination of two laws and a constant to form a *universal gas equation*. The ideal gas law is expressed in the equation PV = RT, where P is the pressure exerted by 1 mole of gas in a volume V; R is sometimes expressed as nK, where n is Avogadro's number and K is Boltzmann's constant. It is the gas constant at absolute temperature $T = -273.2°C$ in the Kelvin scale, or $R = 8.314$ joules per gram-mole-Kelvin. The ideal gas law can also be determined in a physical sense from the kinetic theory of gases. There are four assumptions for the use of the kinetic theory to derive the law:

1. *The gas within a given volume contains a very large number of molecules, which follows Newton's laws of motion and maintains randomness* (*see* Avogadro's number).
2. *The actual volume of the total mass of the gas molecules is very small compared to the total volume the gas molecules occupy (the molecules are very small).*

3. *The only force acting on the molecules is the force resulting from short-term elastic collision (kinetic energy and conservation of momentum).*
4. *The gas molecules do not attract or repel each other.*

The ideal gas law is a generalized law that relates the temperature, pressure, and volume of a gas under ideal or perfect conditions, which do not exist in nature. It is a combination of Boyle's law (pressure × volume) and Charles' and Gay-Lussac's laws (volume/temperature). The equation describes the behavior of only "real gases," with some accuracy, at relatively high temperatures, and low pressures. For some gases, it is a good approximation at standard temperature and pressure. At extremely high or low temperatures or pressure, the ideal gas law no longer applies to any gas. Understanding the gas laws was the beginning of modern chemistry. These laws have proven invaluable for almost all areas of science.

See also Avogadro; Boyle; Charles; Gay-Lussac

I-HSING'S CONCEPTS OF ASTRONOMY: Astronomy and Mathematics: *I-Hsing* (c.681–727), China.

I-Hsing was an intelligent child who showed extraordinary ability to remember what he learned and observed. At the age of twenty he was known for his knowledge of mathematics related to astronomy. He was called to serve under Empress Wu-Zetian (625–705), the autocratic ruler of China during the Tang Dynasty, but refused and became a Buddhist monk where he received the name I-Hsing (his original birth name is unknown). He is credited with several major achievements.

In the years 723 to 726 he was part of an expedition to measure the length of a meridian line in degrees on Earth's surface by using astronomy. Over the distance of 2,500 kilometers (about 1,550 miles) on this imaginary line, a team erected nine different campsites to make measurements along this line at the same time on June 21st. At noon on this date each station measured the sun's solstice shadow which happens to be the 24 hours (day) with the longest period of daylight. (The summer solstice, for the Northern Hemisphere, occurs when Earth's North Pole is pointing more directly toward the sun at 23½ degrees.) From measurements taken, I-Hsing used this data to calculate the length of a meridian degree. His figure was much too large, but this value was not corrected until the late Middle Ages.

Using his knowledge about the movement of celestial bodies, I-Hsing devised what was known as the "*Dayan* calendar" which was more accurate than any other calendar of that time and was used for almost one hundred years.

I-Hsing may have been one of the first to design an escapement movement for use in "accurate" timekeeping devices. An escapement is a ratchet-like device, usually a cogwheel, that allows periodic movement in one direction. I-Hsing designed a wooden wheel that had scoop-like compartments spaced around the edge of the wheel. These compartments would catch and hold water until the wheel turned forward to a point where the water would spill out and more water would fill the next compartment. His water clock would make exactly one revolution in a twenty-four-hour period and was as accurate as other more elaborate water clocks that did not use an escapement device but rather depended on water dripping through a small orifice at a specific rate and collected in a small graduated tube to mark off time periods. It is difficult to determine when and who invented water clocks and later mechanical clocks. The challenge to invent an accurate timekeeping device was one that puzzled and occupied many scholars in many lands throughout ancient and medieval history. The goal of accurate timekeeping was not achieved until the twentieth century. It was not until the Middle Ages that metal escapement cogwheels were incorporated into mechanical clocks to produce a regular movement. Early mechanical clocks were no more accurate than water clocks, and all of the early types of clocks averaged an error of about fifteen minutes a day.

See also Huygens

INGENHOUSZ'S THEORY OF PHOTOSYNTHESIS: Biology: *Jan Ingenhousz* (1730–1799), Netherlands.

Plants not only produce oxygen in daylight, but also absorb carbon dioxide.

In 1771 Joseph Priestley, an English chemist, demonstrated that plants in a contained environment of carbon dioxide could make the air breathable in that environment. Jan Ingenhousz confirmed Priestley's hypothesis that green plants produce not only a breathable gas, but that the gas was oxygen. He went one step beyond Priestley's statement. Ingenhousz's theory stated that green plants absorb carbon dioxide and emit oxygen when exposed to light by a process, now known as *photosynthesis* (meaning combining or synthesizing by light), and that plants also reverse this process in the dark. To date, no one has been able to artificially replicate this process in the laboratory. Scientists are working to create artificial systems of photosynthesis that will convert solar energy to more useable sources of energy, such as hydrogen, for use as a clean fuel. Recent experiments indicate that an atmosphere rich in carbon dioxide increases the rate of plant growth in nature as well as in greenhouses. Thus, one solution for reducing the amount of carbon dioxide in the atmosphere would be to plant more trees and other green plants. Ingenhousz's theory set the foundation for the concept of the relationship between living things. He demonstrated that animal life is dependent on plant life (oxygen and food), whereas plants depend on animals for carbon dioxide and the products of decomposition of dead animals and the wastes deposited by animals, as well as dead plants, thus establishing an ecological balance between the animal and plant worlds.

See also Lavoisier; Priestley; Sachs

INGOLD'S THEORY FOR THE STRUCTURE OF ORGANIC MOLECULES: Chemistry: *Sir Christopher Kelk Ingold* (1893–1970), England.

If an organic molecule can exist in two different states other than its normal structure, then it can only exist in a hybrid form.

Sir Christopher Ingold called this idea *mesomerism*, which he used to describe a process similar to the resonance or oscillation of molecules in certain types of organic structures as described by Linus Pauling. Ingold was interested in the molecular structures of particular organic compounds that can have two or more molecular structures. The "mesomerism" molecules of these compounds have the same basic structure but with different arrangements of their valence electrons, which led to Pauling's concept of organic molecules existing in an intermediate (hybrid) form. Isomerization (mesomerism) that forms organic compounds does not fit the octet rule for the Periodic Table of the Chemical Elements. Ingold published a paper "Principles of an Electronic Theory of Organic Reactions" that explained his theory in 1934. Other scientists also validated it by measuring bond lengths in these types of organic molecules. His theory led to a better understanding of special types of organic molecules, which became important in the development of new drugs, particularly antibiotics.

See also Pauling

INGRAM'S SICKLE CELL THEORY: Biology: *Vernon Martin Ingram* (1924–2006), United States.

> *Hemoglobin S (HbS) varies from normal hemoglobin A (HbA) in only one amino acid.*

A Chicago physician named James B. Herrick (1861–1954) first described sickle cell disease in 1910. One of Dr. Herrick's patients who came from the West Indies suffered from a form of anemia in which some of the patient's blood cells were sickle shaped (something like an open letter C)—thus the name *sickle cell anemia*. Some years later it was discovered that these special cells were related to a low level of oxygen in the blood. Hemoglobin molecules present in each red blood cell carry oxygen from the lungs to tissues and organs throughout the body and then bring carbon dioxide back to the lungs. In patients with sickle cell disorder, the hemoglobin molecules are abnormal, and after giving up their oxygen, have a tendency to agglomerate, become stiff, and form into sickle shapes and thus are unable to pass through small blood vessels. This "blockage" causes oxygen deprivation, manifesting in pain and damage to tissues and vital organs. The phenomena was further verified in 1927 by E. Vernon Hahn and Elizabeth B. Gillespie, a surgeon and an intern, respectively, at the University of Indiana Medical School in Indianapolis, and in 1940 by Irving J. Sherman, an undergraduate participating in a genetics study at the Johns Hopkins University in Baltimore.

Using new techniques the American physical chemist Linus Pauling and his graduate students at the California Institute of Technology separated type S hemoglobin from normal type A hemoglobin in 1947. The question, still unanswered at that time, was how hemoglobin S (HbS), which caused the debilitating disease, was related to the proteins and amino acids of the blood.

In 1956 Vernon Ingram split hemoglobin into smaller units and separated them further by using electrophoresis. This electrochemical process uses a weak electric charge, causing large molecules to separate from each other into different "paths" or tracks according to their individual characteristics, which provides a means of identifying the components of the original substances. This procedure helped Ingram to determine that the sickle cell hemoglobin was caused by changes in only one of over five hundred amino acids in the human body. The HbS appeared when the *glutamic amino acid* was replaced by the *valine amino acid*. Ingram then determined this was a mutation of the blood cells. The sickle cell disorder consists of at least two varieties of sickle cells. One form is characterized by a severe slackening of the blood flow, resulting in a **reduction** of oxygen in the blood vessels, which causes more restriction of the flow of oxygenated blood to the body's organs. This reduction of oxygen is the cause of genetic sickle cell anemia. Another kind is called a trait, which is not as devastating as the anemia form. A test for the presence of sickle cell disorders exists, but it cannot distinguish between the two types. Sickle cell disease is the first-known genetic disease to be identified. So far, there is only one drug used to prevent complications of sickle cell disease, but because it is a genetic disorder no drug has yet been found that will cure the disease.

See also Pauling

IPATIEFF'S THEORY OF HIGH-PRESSURE CATALYTIC REACTIONS: Chemistry: *Vladimir Nikolayevitch Ipatieff* (1867–1952), Russia and United States.

By using high temperatures to increase pressure, it is possible to catalyze liquid hydrocarbon molecules.

Ipatieff extended the original research by the French Nobel Laureate in Chemistry Paul Sabatier (1854–1941) who used finely powdered nickel as the catalysis to increase organic catalytic reaction. Sabatier used hydrogen for the catalytic hydrogenation to convert liquid oils (fact) to form more solid hydrocarbons, for example, margarine. Ipatieff designed a type of heavy steel autoclave that he called the "Ipatieff bomb." This device was strong enough to contain a mixture of a liquid and a catalyst whose temperature was raised above its normal boiling point and thus at increased pressures. This led to a method that used high temperatures for catalytic reactions that was much more efficient in creating organic hydrocarbon polymer compounds.

Valdimir Ipatieff was born, raised, and educated in Russia and was responsible for establishing several chemical research facilities for explosives and synthetic rubber. Lenin made him a lieutenant general of all military research in Russia and head of the Soviet chemical industry. Due to the fact that he was a soldier and former follower of the deposed Russian Czar Nicholas, whose entire family was murdered by revolutionists, as well as being dissatisfied with the Communist government, he felt threatened. During a trip to Germany to visit a friend, he emigrated to the United States rather than return home. Although he had no visa when he arrived in Chicago, an oil company supported him as a professor at Northwestern University to continue his research in petroleum chemistry. He and his assistant, the Polish chemist Herman Pines (1902–1996), expanded their research that led to the use of an acid to act as a catalyst for low-temperature organic reactions. In turn, this research led to the development of a method of synthesizing petrochemicals to form iso-octane, as well as other petroleum derivatives, that greatly improved the quality of gasoline by increasing its octane level, thus greatly enhancing the level of performance of airplanes. During World War II, the improved 100-octane aviation gasoline greatly increased the speed of the American and British warplanes, and thus was a major contributing factor in the defeat of the German Luftwaffe (air force). The use of catalytic chemistry was considered a major contribution to the Allied victory over Germany. The use of catalysts in the petroleum industry is directly responsible for the abundance of products manufactured from crude oil today.

See also Adams; Wilkinson

ISAACS' THEORY OF PROTEINS ATTACKING VIRUSES: Biology: *Alick Isaacs* (1921–1967), England.

> *When under attack by a virus, animal cells are stimulated to produce a protein (interferon) that interrupts the growth of the virus.*

Alick Isaacs' study of various genetic varieties of the influenza virus led to his investigation of how the human body responds to different variations of a particular virus. He discovered a low-molecular-weight protein that had some effect on the way a virus multiplied and mutated. He named this newly identified protein *interferon* (also known as IFN). Interferon is a natural protein produced by the cells of the immune systems of animals. There are several classes and types of interferon that attacked foreign agents such as virus, bacteria, parasites, and tumor cells that can damage the animal's tissues and organs. It enters the bloodstream automatically whenever a virus invades the body. Although the body produces only small amounts of interferon, it enables healthy cells to manufacture an **enzyme** that counters the viral infection. As a natural component of an animal's body, it is referred to as a *biopharmaceutical*. Each species of animal, including humans, produces its own type of interferon, which cannot be interchanged between species. The human body produces three types of interferon: 1) type I is divided into *alpha, beta, omega, kappa zeta, tau*, and *delta* sub types; 2) type II, or *gamma* is a single subtype; and 3) type III, *lambda* with three different subtypes. However, all interferon is produced by only one type of cell but can act as a "trigger" to help other cells produce more cells to fight a disease. When first discovered, interferon was very expensive to produce because the human body produces only minute amounts. However, it is available now in large quantities due to the genetic engineering of the protein molecule. It is used to treat a variety of diseases, including liver disorders, such as hepatitis C, hairy cell leukemia, Kaposi's sarcoma, multiple sclerosis, genital warts, and diseases of the gastrointestinal tract.

J

JACOB–MONOD THEORY OF REGULATOR GENES: Biology (Genetics): *François Jacob* 1920–), France. François Jacob shared the 1965 Nobel Prize for Physiology or Medicine with Jacques Monod and André Lwoff (1902–1994).

> *A group of genes, called the ''operon'' genes, is expressed as a single unit that is responsible for regulating proteins.*

After receiving his medical degree from the University of Paris in 1947, François Jacob began working with others at the Pasteur Institute on the genetic material found in viruses. He and a colleague at the Institute, the French geneticist Elie Wollman (1917–), introduced the term "episomes" to describe the genes that sometimes have a separate existence in cells of a host, and yet at other times are integrated into chromosomes of cells that replicate themselves along with the chromosomes. During their studies they found that episomes act as viruses that infect bacteria as they are transferred to the genetic material of the bacteria cells. Following this research Jacob joined forces with the French biologist Jacques Monod (1910–1976) and the American biochemist Arthur Pardee (1921–) to expand his research on the regulation of gene activity. They coined the term "operon" for a group of genes—the *promoter* and the *operator* genes as well as the *structural* genes that provide the RNA code for specific proteins through a process called "transcription" of RNA and DNA. These operons are linked to specific repressor or activator genes and act as regulators that either shut down or turn on other genes. They are related to enzymes required for biosynthetic processes and regulate the production of proteins. The first operon discovered was called the "lac operon" that consisted of structural genes, a promoter gene, a terminator gene, and an operator gene. Most operons that have been studied are found in *E. coli* bacteria.

See also Lederberg; Robbins; Tatum

JANSKY'S THEORY OF STELLAR RADIO INTERFERENCE: Physics (Engineering): *Karl Jansky* (1905–1950), United States.

Unexplained radio interference on Earth originates in space.

Karl Jansky was assigned the task of solving the problem of radio noise interference in shortwave transatlantic radio-telephone transmission. He devised a rotating linear directional antenna that he mounted on an automobile wheel, enabling him to turn it through 360 degrees. Using this antenna, he identified a number of sources of "noise" or static originating in the atmosphere, some of which came from industrial sources, as well as thunderstorms. However, he continued to believe some of these unwanted signals originated from the sun. After more study he realized this was not possible because the time of the peak noise was shifting as Earth revolved around the sun during a twelve-month period. He finally rejected this solar theory when he was unable to detect a signal from the sun during the partial solar eclipse of August 31, 1932. Jansky's theory, which he published in 1932, stated there were two sources in space from which these radio signals emanated. One source was the Milky Way galaxy. The strongest signals came from the direction of the constellation Sagittarius configuration of stars and galaxies. According to the astronomers Harlow Shapley and Jan H. Oort, this is in the direction of the center of the Milky Way. Jansky's work and theory led to the development of the important fields of radio and X-ray astronomy. Currently, manmade satellites use his concept to explore radiation from deep space. X-ray astronomy measures the leftover radiation from the big bang at the time of the origin of the universe. These observations are expected to explain the age and nature of our universe more accurately. Unfortunately Jansky developed liver disease and died at the age of 45 before he could continue his promising research in the field of radio astronomy. The unit for the strength of transmitted radio waves was named the *Jansky* in his honor.

JANSSEN'S THEORY OF SPECTRAL LINES OF SUNLIGHT: Astronomy: *Pierre Jules Cesar Janssen* (1824–1907), France.

The bright yellow lines observed in the spectrum during a solar eclipse are the same lines observed when the moon does not block the sun. This is evidence of a new element never detected on Earth.

Over a period of nearly fifty years Pierre Janssen traveled on many expeditions around the world to view total eclipses of the sun. He was aware that the bright line he observed in his spectroscope when viewing light from the unobstructed sun could be considered evidence of the element hydrogen in the sun itself. On a trip to Guntur, India, he used a spectroscope to observe a total eclipse on August 18, 1868. During this eclipse, even though the moon passing in front of the sun blocked it out and there was no direct sunlight, there were bursts of light appearing around the edges of the moon. These prominences of light are known as the **chromosphere**. Janssen noticed a bright yellow line in his instrument that had a wavelength of 587.49 mm during the eclipse when there was no direct sunlight. He was criticized because never before had an element been discovered in space. A few months later, Norman Lockyer, an English astronomer, observed the same yellow lines and named it "helium" that he thought was a new form of hydrogen. In 1895 William Ramsay of Scotland discovered an element on Earth with the same spectroscopic wavelength as Janssens' spectral lines. Ramsay is given credit for the discovery of helium, although it was Janssen who first detected helium in the sun.

Pierre Janssen was a well-traveled astronomer. On one trip to Peru in 1857 he was able to detect and establish the magnetic equator for Earth. He also viewed two transits of Venus and viewed many solar eclipses. During the early days of the Franco-Prussian conflict in 1870 he escaped from the siege of Paris by hot-air balloon to complete a tour to observe an eclipse. Due to cloud cover, his efforts proved unsuccessful.

JEANS' TIDAL HYPOTHESIS FOR THE ORIGIN OF THE PLANETS: Astronomy: *James Hopwood Jeans* (1877–1946), England.

> *A passing star pulled off a lump of sun matter, which later broke apart and solidified into the planets as they revolved around the more massive sun.*

Prior to Jeans' time, the accepted concept for the origin of the planets was Pierre Simon Laplace's **nebula** hypothesis, that a contracting cloud of dust and gas from the sun formed the planets. A different tidal hypothesis was proposed by James Jeans, which asserted a large star passed close to our sun, causing a cigar-shaped protrusion of gas and matter to be pulled off the sun. This oblong formation of gas and other sun chemicals coalesced to form planets as they were sent into orbits around the sun, as they were affected by the sun's great gravitational force. Some years later other astronomers rejected Jeans' theory. They resurrected and revised Laplace's condensation hypothesis, which is still accepted by some astrophysicists. Later, Jeans demonstrated that all the outer planets had very cold atmospheres, but residual internal heat keeps them relatively warm. In 1923 Jeans conducted research at the Mount Wilson Observatory in Pasadena, California. Sir James Hopwood Jeans, knighted in 1928, was professor of astronomy at the Royal Institute in London from 1935 until his death in 1946. He wrote several excellent books including some textbooks in science. Some of his early titles are *Dynamical Theory of Gases* and *Mathematical Theory of Electricity and Magnetism*, both in the early 1900s. Later he wrote important books on astronomy, including *Problems of Cosmogony and Stellar Dynamics*, *Astronomy and Cosmogony*, *The Universe Around Us*, and *The Mysterious Universe*. These last two were written for the general public and were his most popular.

See also Hale; Laplace

JEFFREYS' THEORY OF GENETIC (DNA) PROFILING: Biology (Genetics). *Alec John Jeffreys* (1950–), London.

> *Parts of the gene that code for the protein myoglobin consist of a short sequence of DNA that is repeated.*

After receiving his PhD degree at Oxford and spending two years there as a research assistant, Alec Jeffreys became a professor of genetics at the University of Leicester in England in 1977. While there, he and his colleague Richard Flavell (1945–) made the important discovery that developed into what is known today as "DNA fingerprinting."

Rather than referring to it as ''DNA fingerprinting,'' the procedure might more properly be called ''DNA testing,'' ''DNA typing, or ''DNA profiling'' because prints from the fingertips are not part of the samples used in the collection process. Although there is only a one in fifty billion chance that two people will have the same DNA sequence, unlike fingerprints that are different for all people including identical twins, identical twins can have the same DNA. In the recent past DNA profiling has not always been considered ''foolproof'' in courts of law. For example, during the O.J. Simpson murder trial in 1995 the jury ignored the evidence of his DNA found at the scene of the crime. Since that time the process for collecting and testing the samples of DNA and related laboratory procedures have greatly improved to the point that the courts and juries are now more likely to accept DNA evidence related to crimes.

Some of the other uses for the technique are building a national or world data bank of individuals' DNA; diagnosing diseases such as cystic fibrosis, sickle cell anemia, hemophilia, Huntington's disease, and several other possible genetic diseases. It can also be used to test for paternity, as well as for personal identification in case of death where the body is unrecognizable, as in the 9/11 disaster. The process can be used on blood-stained clothing or semen that is decades old. A famous example: the blood from Abraham Lincoln's stained clothing was analyzed and used to diagnose him as having a genetic disorder known as Marfan's Syndrome.

The original idea of taking an ink print of individual fingertips was based on the fact that no two people (including identical twins) have the same swirl pattern (ridges) on the tips of their fingers. This system has been used successfully for many years to identify specific individuals for many purposes, but the patterns of ridges on the fingertips can be altered by surgery, so the method is not foolproof. As a geneticist, Jeffreys was aware that individuals within the same species have most of their DNA sequence in common. In other words, our genetic makeup is very similar to other humans. In fact, chimpanzees have about 98.5% of the same DNA as humans—but that 1.5% difference constitutes the distinction between *Homo sapiens* (hominids) and apes (hominoids).

DNA is the same for all human tissues, organs, and products of these tissues and organs, including blood, semen, and saliva. However, while working with the gene that codes the protein myoglobin, Jeffreys observed that a short part of the gene repeated itself in a repetitive sequence. More important, the number of times this sequence was repeated was different in each individual's DNA. The amount of repeats was named VNTRs which means "variable number tandem repeats." At first Jeffreys did not understand the real significance of this difference in the DNA of every individual. He soon realized that the marker sequences could be used to identify individuals, just as physical fingerprints do, by using an enzyme to split the DNA molecule that can then be treated and identified by a process called **electrophoresis**. This DNA "fingerprinting" (which is really a misnomer) requires only a very small sample of a person's DNA.

Jeffreys' 1984 "accidental" discovery was first used in Narborough, Leicestershire, England, to solve rape and murder cases involving two young girls, one in 1983 and the other in 1986. Blood samples that were taken from nearly 5,000 boys and men from the area of the crime were sent to Jeffreys for DNA analysis. None matched the semen recovered from the girls. Sometime later, another sample from a twenty-eight-year-old cake decorator, Colin Pitchfork, was also sent to Jeffreys for analysis. Pitchfork's DNA was screened, and it matched the semen recovered from both victims. As a result, Pitchfork was convicted in 1987 of these two crimes.

See also Crick; Franklin; Pauling; Watson (James)

JEFFREYS' SEISMOLOGICAL THEORIES: Astronomy (Geophysics): *Sir Harold Jeffreys* (1891–1989), England.

Earth's core is liquid.

Harold Jeffreys was not the first to theorize that the core of Earth is liquid ever since it was determined by the German-born seismologist Beno Gutenberg (1889–1960) that there was a central core inside Earth. Earth's internal structure was studied by several geologists including Richard D. Oldham (1858–1936), Herbert H. Turner (1861–1930), and Perry Byerly (1897–1978), as well as Keith E. Bullen (1906–1976) who jointly published with Jeffreys the seismological tables now known as the "JB tables" that give the travel times of seismic waves. These tables include a tabular list of all the main seismic phases for the focal points of earthquakes at different depths in Earth related to different locations on the surface of Earth. Jeffreys established travel times for the arrival of what are known as the P waves (the primary waves originating from the earthquake) from the travel time for S waves (the secondary waves of the earthquake). With the knowledge of the speed and travel times of P and S waves, the distance between the observers on Earth to the source of the earthquake could then be established. These tables also could be used to authenticate the depth of an internal "quake" and its distance from an observer on Earth. His data and theory also supported the concept of substantial differences in the geology and composition of the internal "spheres" of Earth.

Harold Jeffreys further developed James Jeans' planetesimal theory that hypothesized that a huge tidal wave on the surface of the sun caused by a passing or possibly a colliding star resulted in a long filament of matter being "pulled" out of the sun and in time through the effects of gravity and the matter's momentum on this filament of matter became the solar system's planets, comets, and meteors. This theory was first conceived by the American geologist Thomas C. Chamberlin (1843–1928) and the American astronomer Forest R. Moulton (1872–1952) in the early 1900s. Jeffreys was also a mathematician who further developed the concept of probability statistics that became useful in the fields of physics and astronomy. He published over three hundred scientific papers and published seven books including *The Earth: Its Origin, History, and Physical Constitution* and *Theory of Probability and Mathematical Physics*, as well as several important publications on geology and seismology.

See also Agricola; Chang; Laplace; Richter; Ulam

JENNER'S INOCULATION HYPOTHESIS: Biology: *Edward Jenner* (1749–1823), England.

Injecting humans with cowpox fluid will immunize them from smallpox.

At a young age, Edward Jenner was apprenticed to a surgeon in London where he studied medicine before returning to his home in the county of Gloucestershire as a country doctor. At that time smallpox killed many people in England as well as on the European continent. An old English wives' tale asserting that milkmaids who had contracted cowpox would not be susceptible to the more deadly smallpox was widely

> Even today, there is still some criticism of Jenner's inoculation procedures due to our current laws restricting the use of humans as experimental subjects without proper consent, which did not exist before the mid-twentieth century. Regardless of the current laws restricting the use of humans as experimental subjects without informed consent, many states require preschool children to be vaccinated against several communicable diseases before entering school. A few parents refuse to have their children vaccinated for religious and other reasons, including the belief that many of the vaccines are unsafe. If large numbers of children do not receive the required vaccinations, there is a possibility of an epidemic of one or more of these communicable diseases.

accepted in this rural area. Jenner was a research-oriented physician who based his research on case studies and clinical observations, which proved to be the forerunner of modern medical research of disease-causing bacteria and viruses. Today, he is considered to have laid the groundwork of the modern science of immunology. This "old wives tale" belief led Edward Jenner to hypothesize that deliberately infecting people with cowpox germs would prevent them from contracting smallpox. To do this, he extracted some fluid from a cowpox blister on Sarah Nelmes, a milkmaid. Using a procedure Jenner later named *vaccination* (from two Latin words: *vacca* for "cow" and *vaccinia* for "cowpox"), he injected this fluid into an eight-year-old boy, James Phipps. Jenner is also credited with introducing the term "virus." Six weeks after the cowpox injection, Jenner injected the boy with fluid from a smallpox blister. The boy did not contract smallpox. After some additional trials (some not always successful and a few subjects did develop smallpox), Jenner published his results. The public reaction to his experiment was, and still is, mixed, and at one time his vaccinations were banned in England. Then soon after a serious outbreak of smallpox, all English children were required to be inoculated.

In the seventeenth century about 10% of all deaths in London were attributed to smallpox. During the eighteenth century smallpox vaccination became more acceptable. Due to the success of Jenner's controversial experiment, the death rate from smallpox during the nineteenth century dropped from about forty per ten thousand people to about one in every ten thousand. Currently, the World Health Organization (WHO) claims that smallpox has been eradicated. However, it can still flare up in rural areas of India, Asia, and Africa, where many children are not inoculated. Smallpox viruses are also being produced and stored for use as a biological weapon by some countries. Several industrialized nations are vulnerable, including the United States, because their citizens are no longer required to be vaccinated against the disease. However, travelers to "at-risk" countries are required to receive the smallpox vaccination before departing for their destination.

See also Lister

JERNE'S THEORY OF CLONAL SELECTION OF ANTIBODIES: Biology: *Niels Kaj Jerne* (1911–1994), Denmark. Niels Jerne shared the 1984 Nobel Prize for Physiology or Medicine with César Milstein and Georges Köhler.

> *Diverse antibodies are present in humans at birth and, when attacked by a virus, can produce additional antibodies.*

An antibody is a protein found in the blood that responds to its complementary antigen. It is also known as an immune body.

Niels Jerne was aware of the concept that the body's lymphocytes (white blood cells) produce a wide range of various types of antibodies that attack specific bacterial and viral infections. Jerne based his theory on the belief that each cell that produces a specific **antibody** is present in the body from birth, possibly transferred by the baby's mother or the result of cell mutation in the newborn. Bacteria or viruses infect the body by releasing their particular set of chemicals. The infected person's antibodies cause the lymphocytes related to particular bacteria or viruses to divide, producing clone cells that greatly increase the number of antibodies available to fight that specific infection. This theory led to the question of how all this genetic information was included in these original, at-birth cells. Jerne developed the concept of *somatic mutation*. Somatic body cells are the many types of cells that make up the tissues in the body, with the exception of the reproductive germ cells (ova and sperm). This cell mutation concept was the forerunner to Susumu Tonegawa's more complex antibody interactive control mechanism referred to as the "jumping genes" theory. Niels Jerne proposed a theory on the functioning of the immune system, but he neglected to consider the multitude of chemical compounds involved in modulating the immune system. His work and theory are responsible in large part for the current study of the immune system.

See also Koch

JOHANSON'S THEORY FOR THE EVOLUTION OF HUMANS: Anthropology: *Donald Carl Johanson* (1943–), United States.

> *In the pre-*Homo sapiens *species,* Australopithecus afarensis, *the males were larger than the females, indicating they did the hunting while females gathered and cooked food.*

In Ethiopia in 1972, Donald Johanson discovered several bones of a fossilized skeleton, which he identified as a small, three and one-half foot female who was as much a bowlegged, upright-walking, chimpanzee-like creature as she was human. The bones are believed to be between 3.2 and 3.8 million years old. He named this small-brained fossilized female Lucy, after the Beatles' song "Lucy in the Sky with Diamonds," which was playing over and over on the camp's phonograph on the night he made the discovery. Johanson named his new species *Australopithecus afarensis*. Previous to Johanson's discovery, Raymond Dart (1893–1988), the Australian anatomist and anthropologist, discovered a skull in a box of fossil-ferrous rocks that was sent to him by the owner of a rock quarry in Africa. Dart later identified the find as a new species of fossil primate that predated various species of *Homo sapiens*. Dart named this new species, *Australopithecus africanus* (meaning southern African ape). Although both discoveries were made in Africa, they were discovered in different regions. Eventually and not unexpectedly, other anthropologists challenged Johanson's discovery and theories. Johanson stated that bipedalism (walking upright on two legs) preceded the development of the large brain capacity in humans. This contradicted existing theory that claimed that prehumans developed large brains before they became bipedal. He also claimed that females of this prehistoric species stayed "home," pregnant, caring for children, and cooking the bounty secured by the larger and stronger male hunters. Adrienne Zihlman, an anthropologist, primatologist, and self-proclaimed feminist from the University of

> Several years ago anthropologists announced the discovery of one small skull plus a few other bones on the Indonesian island known as Flores. They claimed that this skull and bones were of a newly discovered species of miniature prehumans. The scientists who discovered these bones named the new species "hobbits" (*see* J. R. Tolkien's books) that lived on the island from as early as thirteen thousand and possibly as far back as ninety-five thousand years ago. The October 28, 2004 issue of the journal *Nature* reported that the discoverers gave the "hobbits" the official name of *Homo floresiensis* after the island where not only the bones were found but also rather sophisticated stone tools recovered from a cave named Liang Bua. These little prehumans were slightly more than three feet tall with heads the size of chimpanzees. Some scientists speculated that this prehuman species were the ancient ancestors of the later species known as *Homo erectus* that spread across Africa into Europe and Asia about a million years ago. This would also make them a distant past relative to *Homo sapiens* who emerged as recently as one hundred thousand years ago (some anthropologists believe that prehumans existed on Earth more three million years ago although there is scant fossil evidence to support this theory). More recent examinations by skeptical anthropologists challenge not only the authenticity of the hobbit fossils, but also the importance of this "new" species to the evolutionary processes leading to modern humans.

California, Santa Cruz, challenged this theory. Zihlman claimed that this is a typical male anthropologist's sexist interpretation, while Johanson claimed that Zihlman's interpretation of the fossil record was that of an anthropologist seeking recognition of the role of females in the discipline, whereas it is more acceptable to consider all fields of science, including anthropology as genderless. Anthropologist Richard Leakey, son of the famous anthropologist Louis Leakey, claimed the various human species could be traced back even further in history than the fossils of *A. afarensis* (Lucy). He also claimed there were probably two or more branches to the ancestral tree of modern humans, not one as Johanson claimed. Others declared that because Johanson gathered the bones from different sites, the partially completed skeleton was not of a single person or even a female. Additional pre-*H. sapiens* fossils found in Africa seem to confirm Johanson's theory. Although Johanson's discovery and theories significantly contributed to science, some doubt remains as to the history of the ancestors of early *H.sapiens*. In addition, it has been claimed that *Australopithecus* is not a separate distinct species in the continued evolution of humans but may be just another unsuccessful, extinct proto-human species similar to the Neanderthals.

See also Leakeys

JOLIOT-CURIES' THEORY OF ARTIFICIAL RADIOACTIVITY: Physics: *Frédéric Joliot-Curie* (1900–1958) and *Irène Joliot-Curie* (1897–1956), France. Frédéric and Irène Joliot-Curie jointly received the 1935 Nobel Prize for Chemistry.

Radioactive elements can be artificially manufactured from stable elements.

Frédéric and Irène Joliot-Curie's experiment entailed bombarding the element boron (B-10) with two alpha particles (α), which are the nuclei of the element helium generated from the decay of the element polonium. This nuclear bombardment resulted in the formation of radioactive nitrogen (N-14). The bombardment of the lighter element boron with alpha particles changed (transmuted) boron to nitrogen, thus making a radioactive form of that element (B-10 + $\alpha \rightarrow$ N-14). In another experiment, they bombarded aluminum with alpha particles. After a short period of time they removed the source of alpha particles and noticed that though the aluminum continued to be radioactive, it was only for a short period of time. The reason: the aluminum atoms absorbed alpha particles and transmutated into an isotope of the element silicon that had a half-life of just 3.5 minutes (Al-26 + $\alpha \rightarrow$ Si-28).

Otto Hahn recognized the importance of this discovery and realized that the reaction could lead to the fission of the nuclei of larger elements and possibly result in a nuclear chain reaction. These discoveries led to the production of controlled nuclear fission chain reactions that have produced not only the atom (nuclear fission) bomb, but also electricity, and just as important, the production of a great variety of radioactive isotopes that are used in the medical and other industries. Note: a nuclear chain reaction occurs when a fissionable heavy element produces a succession of nuclear divisions that set neutrons free that then interact with and split other nuclei. This ends in stable nuclei of lighter elements, or if uncontrolled fission occurs, the reaction will end as a nuclear (atomic) explosion. A typical nuclear fission reaction starts by a heavy element absorbing and then producing neutrons. For example:

$$^{0}\text{n} \rightarrow {}^{235}\text{U} \rightarrow {}^{236}\text{U} \rightarrow {}^{93}\text{Rb} + {}^{141}\text{Cs} \rightarrow 2^{0}\text{n}$$

Irène, the daughter of Pierre and Marie Curie, married Frédéric Joliot the son of a local tradesman in 1926. After the marriage, Frédéric and Irène combined their surnames as Joliot-Curie. Frédéric began his research career at the Radium Institute in Paris under the guidance of Marie Curie, his mother-in-law, where he received his doctorate. He served in the French Resistance during World War II. In 1956 he became head of the Radium Institute, which was founded in 1914 by the University of Paris primarily because of the research efforts of Madame Curie.

Irène Joliot-Curie received her doctorate of science in 1925, also from the Radium Institute, based on her research on alpha rays of polonium (discovered by her mother). During World War II she served as a nurse radiographer.

Together and individually, Frédéric and Irène did important work in both natural and artificial radioactivity, the transmutation of heavier elements into lighter elements (e.g., uranium into lead), and the production of new radioactive elements and isotopes of elements. For their work, they jointly received the Nobel Prize for their discovery of artificial radioactivity and anticipated Otto Hahn's discovery of nuclear fission.

See also Curie (Pierre and Marie); Hahn

JOSEPHSON'S THEORY OF SEMICONDUCTORS: Physics: *Brian David Josephson* (1940–), Wales. Brian Josephson shared the 1973 Nobel Prize for Physics with Leo Esaki and Ivar Giaevar.

A DC voltage applied across a thin insulator between two superconductors produces a small alternating current whose frequency varies inversely to the voltage.

The BCS theory (named after John Bardeen, Leon Cooper, and John Schrieffer) demonstrated the concept of superconductivity at super low temperatures. The BCS theory states that under conditions of near absolute zero, electrons travel in pairs rather than individually, as the result of vibrations of the atoms. Josephson demonstrated this

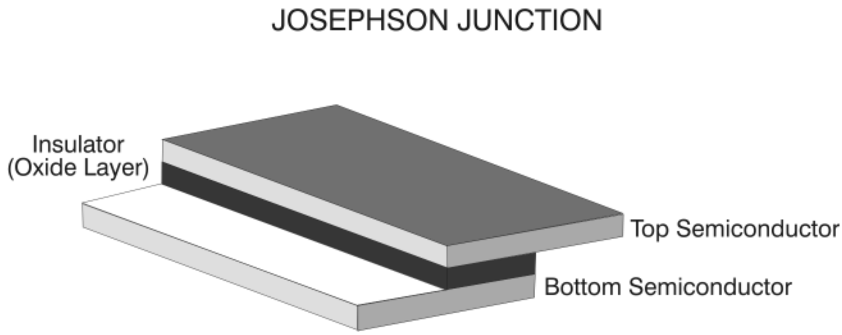


Figure J1. The Josephson Junction controls the operation of many devices that use semiconductors.

phenomenon by placing an insulator between two electron-conducting plates of metal known as a *Josephson junction*. The effects of these electrons flowing across this partially insulated junction produced a semiconducting flow of current known as the *Josephson effect*. A current can continue to flow across this junction for a short period of time even when the voltage is temporarily removed. In addition, a small current can produce an alternating current on the other side of the junction whose frequency varies inversely with the applied voltage. By using paired electrons Josephson maintained a tunneling effect that allowed the alternating super current to flow across the thin, insulating barrier of the **semiconductor.** Thus by changing the current's frequency the Josephson junction could be used as a means of controlling electronic devices somewhat like a switch.

This revolutionized the electronics industry and modern life. Today, the separator between the plates of semiconductors can be applied to a thickness of only one or a few atoms of material. Semiconductors are used in sensitive instruments to make accurate magnetic and electrical field measurements. Some applications of the Josephson junction are the detection of microwave frequencies, magnetometers, and thermometers to measure near absolute zero temperatures, and detection and amplification of electromagnetic signals. Of more importance, semiconductors are used to make high-speed (almost the speed of light) switching devices, which make modern computers possible.

See also Bardeen; Brattain; Shockley

JOULE'S LAW AND THEORIES: Physics: *James Prescott Joule* (1818–1889), Scotland.

Joule's law: *The relationship for heat produced by an electric current in a conductor is related to the resistance of the conductor times the square of the amount of current applied:* $H = RI^2$.

By experimentation, James Joule established the law that states that when a current of voltaic electricity is sent through a metal or other type of conductor, the heat given off over a specific time period is proportional to the resistance of the conductor multiplied by the square of the electric current. The equation for this law is: $H = RI^2$, where H is the rate of the heat given off as watts in joule units, R is the resistance in the conductor in ohms and I^2 is the amount of the current (amps) squared. The application of this law is important in all industries using electricity as a source of energy. The resistance to an electric current flowing through a conductor is analogous to the friction of air, the movement of engine parts, and tires on the road for a moving automobile. The electrical, as well as mechanical, energy is not just "lost," rather it is converted to heat, just as is friction. Joule was interested in improving the mechanical advantage of electric motors, but because they were very primitive during his lifetime, he devoted more of his work to improving the efficiency of steam engines. He accurately predicted that electric motors eventually would replace most other types of mechanical devices.

James Prescott Joule was one of five children in the family of a well-to-do brewery owner. Since he was a sickly child with a spinal deformity, both he and his brother were educated at home until the age of 15 and later by private tutors. The famous English chemist, John Dalton, taught them chemistry, physics, and the methods of scientific experimentation. Later in life Joule acknowledged that John Dalton encouraged him to increase his knowledge of science and of original research. When James' father died, he and his brother ran the brewery, which prevented him from attending a university. However, this did not deter him from setting up a laboratory in his home and continuing his interest in science after his day at the brewery. He became proficient in mathematics and learned how to make accurate measurements in the brewery. His home experiments resulted in his ability to measure slight increases in temperature under various conditions, which led to his theory for the equivalence of work and heat energy. The unit of work and energy was named after him (the Joule, or the symbol "J").

Law for the mechanical equivalent of heat: *A fixed amount of mechanical work (expenditure of energy) ends up in a fixed quantity of heat.*

Earlier in 1798 when Count Rumford was boring out the brass barrels of cannons, he noticed that large amounts of heat were generated. It became obvious that friction generated by the work of turning the bit in the metal resulted in heat. Julius von Mayer also was interested in this relationship and developed a figure for the mechanical equivalent of heat that was not very accurate. James Prescott Joule was the first to consider heat as a form of energy in his calculation. He conducted exacting experiments to determine the amount of heat generated not just by electricity but also by mechanical work. Joule calculated the amount of mechanical work needed to produce an equivalent amount of heat. He demonstrated that 41 million ergs of work produced 1 calorie of heat, which is now known as the *mechanical equivalent of heat.* Since 10 million ergs are equal to 1 joule, named after James Joule, 4.18 joules are then equal to 1 calorie of heat. Joule's work enabled others to perfect the law for the conservation of energy, which states that energy, like mass, cannot be created or destroyed but can be changed from one form to another.

Joule–Thomson effect: *When a gas expands, its internal energy decreases.*

James Joule collaborated with Lord William Thomson (later known as Lord Kelvin) to devise the Joule–Thomson effect, which is related to the kinetic theory of gases. They measured the change in energy involved when the pressure of a compressed gas is released and then expands. As a gas expands, the motion of molecules is reduced. In other words, its internal energy is decreased, and thus its temperature. It can be reheated if it can "consume" energy from its surrounding environment, thus providing a cooling effect to the area around it.

See also Ideal Gas Law; Kelvin

K

KAMERLINGH-ONNES' THEORY OF MATTER AT LOW TEMPERATURES: Physics: *Heike Kamerlingh-Onnes* (1853–1926), Netherlands. Heike Kamerlingh-Onnes was awarded the 1913 Nobel Prize for Physics.

Some metals lose their electrical resistance at super-low temperatures.

Heike Kamerlingh-Onnes experimented with the properties of matter at low temperatures and improved on the apparatus and procedures employed by Sir James Dewar in the late 1800s. This enabled him to use liquid hydrogen and the Joule–Thomson evaporation effect to cool helium to a temperature of 18 kelvin (which is 18° above absolute zero). After cooling the gas still more and by allowing it to expand through a nozzle, he determined liquid helium has a boiling point of 4.25 kelvin (it was known at the time that when a gas expands, its temperature is reduced). When the liquid helium is in an insulated container and the vapors are rapidly pumped away, the liquid helium is cooled still further to just 0.8 kelvin. This was as close to absolute zero as had so far been reached at that time in history. He was the first to study the nature of materials at this extremely low temperature and ascertain that molecular activity (kinetic energy) almost ceases at this temperature. This was the beginning of the science of **cryogenics**, which led to the observation of superconductivity, where metals lose their resistance to electricity, thus enabling electric currents to pass through wires without generating heat by internal resistance. In 1911 he determined that metals such as lead, tin, and mercury become superconductors at these very low temperatures. Today, scientists know that at least two dozen elements and many hundreds of compounds become superconductive at near absolute zero temperatures. In 1986 a ceramic-type compound exhibited superconductivity at about -196°C, which just happens to be the temperature at which nitrogen gas becomes a liquid. This is important because it is easier to reduce temperatures to near absolute zero using helium, but its source is limited and thus is very expensive. Although nitrogen can also be liquefied and used for low-temperature research, it is not as efficient for this purpose as is helium, but the supply of nitrogen gas is almost unlimited as four-fifths of air is nitrogen. Liquid nitrogen is now used for supercooled magnets in particle accelerators and magnetic resonance imaging (MRI) equipment in the medical industry. The size of the magnets required for this equipment can be greatly reduced through the use of supercooled magnets. Scientists have not found many other practical uses for superconductivity because of the difficulty of achieving and maintaining sufficiently low temperatures. Currently, scientists are at work attempting to achieve warm, ambient air superconductivity, which will provide the same low resistance to electricity but at temperatures much higher than absolute zero. Physicists in several countries claimed to have produced materials that become supercondutive at room temperatures. Most of these experiments can't be replicated even though a few exhibit some characteristics of superconductivity. It is hoped this research will succeed in achieving superconductivity at normal temperatures of room air. Such an accomplishment will result in the development of more cost-effective methods for transmitting electricity, as well as in the production of supermagnets to levitate high-speed trains.

See also Dewar; Joule; Kapitsa

KAPITSA'S THEORY OF SUPERFLUID FLOW: Physics: *Pyotr Leonidovich Kapitsa (or Pjotr L. Kapitza)* (1894–1984), Russia. Pyotr Leonidovich Kapitsa shared the 1978 Nobel Prize for Physics with Arno Allan Penzias and Robert Woodrow Wilson.

Thin film-vapor systems exhibit superflow properties at very low temperatures, with the resistance to flow increasing as the film's thickness increases.

Pyotr Leonidovich Kapitsa developed an improved method for liquefying air, which enabled him to study the properties of liquid helium. He determined that liquid helium, known as He-II, behaves as a "superfluid" at near absolute zero and exhibits very unusual flow characteristics. At this temperature liquid helium appears to be in a perfect atomic macroscopic *quantum* state with perfect atomic order. He-II exhibits a super-thin film that manifests some novel forms of internal convection, including its ability to flow up the sides of its container, even when the container is closed. Kapitsa's methods for liquefying gases were used to facilitate the commercial production of liquid oxygen, nitrogen, hydrogen, and helium. Large-scale production of these gases enabled the development of very high magnetic fields used in many areas of research and technology, such as particle accelerators and nuclear magnetic resonance (NMR) instruments.

See also Kamerlingh-Onnes; Kusch

KAPTEYN'S THEORY OF GALACTIC ROTATION: Astronomy: *Jacobus Cornelius Kapteyn* (1851–1922), Netherlands.

Stars in the sky move in two different streams in two different directions.

Kapteyn was an excellent observer of stars. In 1897 he discovered what became known as "Kapteyn's Star" that exhibited the greatest proportion of proper motion (8.73 seconds of annual motion) of any star known at that time. Later, Kapteyn's Star was relegated to second in its proper motion when Barnard's Star was discovered to exhibit 10.3 seconds of annual motion (Barnard's Star is named after the noted American astronomer Edward Emerson Barnard (1857–1923) who in 1916 found that it had the largest proportion of proper motion of all known stars). In 1904 Kapteyn cataloged over 454,000 stars of the Southern Hemisphere by using the photographic plates made by the Scottish astronomer David Gill (1843–1914). While studying these photographic plates, as well as doing his own observations, Kapteyn hypothesized that the stars in the heavens were moving and heading in two different directions. One stream consisting of about three-fifths of all the stars in galaxies was heading toward the constellation Orion and the other stream consisting of about two-fifths of all the known stars was heading in the direction of the constellation Scorpius. More important, the line between them led through the Milky Way galaxy that was originally discovered by William Herschel. Herschel calculated the size of the Milky Way galaxy as fifty-five thousand light-years across and eleven-thousand light-years thick. Using this model, Kapteyn proposed an arrangement and motion of the sidereal system, which he published in 1922, as a lens-shaped, rotating island universe that was denser at its center and less dense at the edges. This became known as "Kapteyn's Universe," which he estimated as forty-thousand light-years in size with the sun at its center. A more up-to-date figure for the size of the Milky Way is one hundred thousand light years across from edge to edge. At that time in astronomy's history, Kapteyn's and other astronomers' concept of a universe was limited to this single large galactic star system. Today astronomers believe that the universe is everything that can be observed and from which we can gain knowledge. This includes a multitude of "island universes" or galaxies.

See also Herschel; Oort

KARLE'S THEORY FOR DETERMINING MOLECULAR STRUCTURE: Physics: *Jerome Karle* (1918–), United States. Jerome Karle shared the 1985 Nobel Prize for Chemistry with Herbert A. Hauptman.

> *Mathematical methods can be used to deduct the molecular structure of chemical compounds and to explain the X-ray patterns formed by the compounds' crystals.*

Jerome Karle began his academic and professional career at the University of Michigan where he met and married his wife, the former Isabella Lugoski (1921–), the renowned X-ray crystallographer and researcher. After completing the requirements for his doctorate at Michigan in 1943, he, along with Isabella, began work on the Manhattan Project at the University of Chicago. After the war, they went to work for the Naval Research Laboratory in Washington, D.C., where they began a life-long career and interest in the structure of crystals. Jerome Karle was concerned with the theoretical and mathematical aspects of crystallography, while Isabella Karle applied the practical application of her husband's research, as well as her own investigations. In every sense of the word, they were a "team."

At the time the Karles moved to the Naval Research Laboratory, they were joined by the American mathematician Herbert Hauptman (1917–). This was the beginning of three decades of collaborative research on crystallography by Karle and Hauptman that culminated in the 1985 Nobel Prize for Chemistry (after leaving the Naval Research Laboratory in 1970, Hauptman became research director of the Medical Foundation of Buffalo). In 1953 Jerome Karle and Herbert Hauptman published a monograph titled "Solution of the Phase Problem I: The Centosymmetric Crystal" in

Jerome Karle was born in New York City, received his undergraduate degree in biology from City College in New York and a master's degree from Harvard, followed by a PhD in physical chemistry from the University of Michigan in 1943. While at the University of Michigan he met and married Isabella Lugoski (1921–) the daughter of Polish immigrants in 1942. She did not hear any English spoken until she entered elementary school. At age 19 Isabella entered the University of Michigan where she received three degrees, including a PhD in physical chemistry in 1944. Jerome and Isabella worked together on the Manhattan Project in Chicago, Illinois, from 1943 to 1944 and as researchers at the Naval Research Laboratory (NRL) in Washington, D.C. Their work progressed from electron diffraction to improved methods of X-ray diffraction for the study of crystallography of matter. She applied her powerful techniques to directly calculate the diffraction patterns of many chemicals that were applied to improved medical procedures. In 1959 Isabella was appointed as head of the X-Ray Diffraction Section for the Structure of Matter at the National Research Laboratory. She has received many awards including the American Chemical Society's Garvan Medal in 1976 and was appointed president of the American Crystallographic Association, also in 1976. She received the 1985 Chemical Pioneer Award by the American Institute of Chemists. Isabella also received the $250,000 Bower Award and Prize for Achievement in Science by the Franklin Institute. However, she did not share in the 1985 Nobel Prize for which the work of her husband and Herbert Hauptman was recognized.

which they described a new method of forming X-ray diffraction patterns of crystals of chemical compounds. This monograph was the foundation for the solution to the "phase" problem of X-ray crystallography. The older, so-called heavy atom procedure that was used to enhance the crystal structure to more clearly indicate the crystal's diffraction pattern involved adding a heavy element to a particular area of the crystal to be studied. This technique was clumsy, and the resulting X-ray diffraction pattern could only be inferred. While at the Naval Research Laboratory, they arrived at a mathematical equation that could explain the arrangement of dots on films that showed the X-ray diffraction of crystals. In other words, using probabilistic methods for newly devised mathematical equation, the crystal's phase structure could be directly determined. This was a great improvement over the old "heavy atom" technique because the equation enabled the exact location of specific atoms within the crystal's molecules to be identified. Thus, the intensity of the "spots" on the film that depicted the types of atoms and their positions within the crystal's structure could be analyzed. It was mainly through the efforts of Isabella Karle, who called attention to the practical applications of crystal diffraction, that other scientists in the field were encouraged to adopt their methods for determining the three-dimensional structure of crystalline compounds. This research technique has applications in numerous fields, including pharmacology, molecular biology, chemistry, physics, metallurgy, geology, and genetics.

See also Franklin (Rosalind)

KEKULE'S THEORY OF CARBON COMPOUNDS: Chemistry: *Friedrich Kekule von Stradonitz* (1829–1896), Germany.

Carbon is a tetravalent atom (a valence of 4) capable of forming ring-type organic molecules as well as linear molecules.

Friedrich Kekule von Stradonitz was the first to propose a structural formula that indicated atoms bonded with each other to form molecules. His study led to the concept of the carbon atom's structure consisting of four (tetravalent) bonds with a central nucleus by which it could form numerous types of molecules (*see* Figure V3 under Van't Hoff). He also related this unique atom to the basic structure of all organic (living) carbon compounds. However, one form of carbon puzzled the chemists of his day. Michael Faraday discovered that the molecule for the aromatic compound benzene contained six carbon atoms with a total of twenty-four shared (bonding) electrons, but benzene also had six hydrogen atoms; however, each hydrogen atom had only one bonding electron. When diagramed as a linear or even a branching molecule, this combination was impossible because each carbon atom had four bonds (valence) and each hydrogen atom had just one bond (valence), thus $6 \times 4 = 24$ for carbon, and $6 \times 1 = 6$ for hydrogen, totaling thirty bonding electrons in all for the molecule. Therefore, there existed an incorrect number of electrons to satisfy the octet rule for a linear structure such as C_6H_6. Reportedly, Kekule solved this problem one night as he dreamed. In his dream he saw different configurations of atoms forming various arrangements. One arrangement resembled a snake eating its own tail (*see* Figure K1).

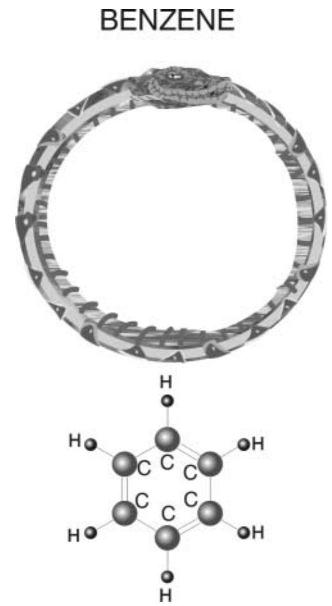


Figure K1. Artist's depiction of Friedrich Kekule's dream of a snake eating its own tail that aided him in solving the problem of the structure for the organic compound benzene, composed of a ring of carbon atoms.

He woke up energized, and, working the rest of the night, came up with the structure of the benzene ring. The ring consisted of each carbon atom sharing two of its four bonding electrons with another carbon atom, one valence electron with a partner on its other side on the ring, and one valence electron with a hydrogen atom outside the ring. The result is the classical benzene, hexagon ring. This answered many questions and was a revolution for organic chemistry. It was then possible to substitute another atom, a *radical*, or a molecule for one of the hydrogen atoms of the six in the ring. This resulted in what is known as a single substitution to form a derivative of the benzene ring (e.g., C_6H_5X). Specifically, if the free radical (a molecular fragment with a single unshared electron and no charge) such as NH_2 were substituted for one of the hydrogen atoms the compound aniline $C_6H_5 \bullet NH_2$ would be the result. In addition, it is possible to combine many of the hexagonal benzene rings to form more complex compounds containing many hexagonal structures. This answered the questions related to the great multiplicity of organic compounds. To some extent, this seems odd because Kekule considered the existence of atoms a metaphysical problem and claimed chemistry was concerned only with arriving at hypotheses that explained chemical structures and reactions. It might be noted that Kekule's rings were originally known as "Kekule Sausages" because he represented his hexagon molecule and its electrons as a somewhat difficult system of circles—not lines as shown in the diagram. The Scottish chemist Alexander Crum Brown (1838–1922) conceived the structure of the benzene ring as it is known today in 1865.

See also Couper

KELVIN'S CONCEPT OF ENERGY: Physics: *William Thomson Kelvin* (known as Lord Kelvin) (1924–1907), Scotland.

Kelvin's theory of thermodynamics: *When a gas cools, loss of volume is less crucial than loss of energy. Kinetic energy (molecular motion or heat) ceases at temperatures approaching absolute zero (zero Kelvin = -273.16°C).*

William Thomson Kelvin was knighted by Queen Victoria and given the title of Lord Kelvin of Largs for his work on electromagnetic fields. Kelvin was familiar with the works of Carnot, Joule, and Clausius, early explorers in the field of thermodynamics where mechanical heat is related to energy. The second law of thermodynamics deals with the concept of entropy, which states *that heat always flows from a warmer object to a cooler environment—and never in the opposite direction*. For example, a hot cup of coffee always cools and will never get warmer than its surroundings unless an external source of heat is applied to the cold coffee. This means that energy in a closed system is striving to reach a state where there is no transfer of energy—equilibrium. Eventually everything will be the same temperature. Another way of saying this is that everything becomes more disorganized (entropy) and "runs downhill" to a common level (equilibrium), unless more energy is pumped into the isolated system. But then it would no longer be a closed system. For instance, if Earth did not receive most of its energy from the sun, everything would run down, and it would soon be a very cold place. Kelvin provided a mathematical formulation of the second law of thermodynamics. Because entropy (disorganization) always increases, Lord Kelvin believed the universe would sometime in the future have maximum entropy and thus a uniform temperature. He called this the heat death of the universe. The first law of thermodynamics relates to the conservation of energy which states *that energy can be neither created nor destroyed but can be transferred from one form to another (e.g., mechanical energy to heat energy, as in rubbing your hands together vigorously, generating friction heat), or chemical energy transformed to light and heat (a burning candle)*. Heat itself is the manifestation of the kinetic energy of molecular motion, whereas the temperature of a substance is proportional to the average motion of the molecules when they are in thermal equilibrium, that is, the temperature is a measure of the average internal energy. Kelvin proposed a new scale for measuring the absolute temperature of matter, which at its zero point would be the lowest temperature possible. He started with what is known as the triple point of pure water, which is about 0.01°C, where equilibrium between the water, ice, and water vapor is established. At this temperature, water can exist in its three physical states at the same time: solid, liquid, and gas. The point was also used to set up the metric temperature scale originally referred to as the Centigrade scale because it was based on a scale of 100 but now referred to as the Celsius scale, where 0 is the freezing point of water (or melting point of ice) and 100 is the boiling point of water, where it attains its gaseous state. Selecting 100-degree units for this scale was arbitrary but assisted in metric calculations. Any units could be used, such as the units for the Fahrenheit temperature scale. Lord Kelvin used the same metric (based on 100) scale and, by extrapolation, arrived at −273°C degrees as the absolute zero point. This point was originally called A, for absolute. Therefore, water freezes at 273 kelvin and boils at 373 kelvin. Absolute zero was later refined to equal −273.16°C, or 0.0 kelvin. This absolute temperature scale, named after Lord Kelvin, provides for the measurement of very cold and very hot temperatures. Because no thermometer has been invented that can measure absolute zero, Lord Kelvin reached this point by theoretical consideration. Some people believe that all molecular motion ceases at this point. This is not quite correct because molecules of solids continue to "vibrate" but not move at random or exhibit any kinetic energy as molecules would in matter at higher temperatures. In other words, the energy has the lowest possible value at absolute zero and the entropy is zero.

Kelvin's theory of electromagnetic fields: *Electromagnetic fields travel through space as do light waves; the electric field vector and the magnetic field vector vibrate in a direction transverse to the direction of the wave propagation.*

Lord Kelvin's theory for electromagnetic fields stated the fields associated with alternating current (**AC**) electricity are waves that travel through space similar to light waves. His theory proved that both the types of waves not only are transverse waves, but also travel at the same speed. Kelvin's theory for electromagnetic fields was put to good use and provided the information necessary to lay the first successful transatlantic telegraph cable. Two previous attempts for an ocean-spanning cable had failed. In addition, his theory led to the electromagnetic theory of light developed by James Clerk Maxwell.

See also Carnot; Joule; Maxwell

KENDALL'S THEORY FOR ISOLATING ADRENAL STEROIDS: Biochemistry: *Edward Calvin Kendall* (1886–1972), United States. Edward Kendall shared the 1950 Nobel Prize for Physiology or Medicine with Philip S. Hench and Tadeus Reichstein.

> *The hormones and amino acids secreted by the adrenal glands are a number of steroids identified as A, B, E, and F that are responsible for many physiological activities of the body.*

Edward Kendall received his academic training at Columbia University in New York where he received his undergraduate and graduate degrees in chemistry. After initially working on research on the thyroid gland for a pharmaceutical company in Michigan and at St. Luke's Hospital in New York, he moved to the Mayo Foundation in 1914. He was appointed head of the Biochemistry Section in their graduate school. He subsequently became a director of the Division of Biochemistry and Professor of Physiological Chemistry. Even after his retirement in 1951, he remained a visiting professor at the Mayo Foundation. While at the Mayo Foundation, Kendall began the research that ultimately led to the discovery of a number of hormones produced by the cortex of the adrenal glands. He found that these adrenal secretions could be isolated and used to treat Addison's disease, as well as rheumatoid arthritis. As is often the case, similar research was being conducted independently in another country, in this case Tadeus Reichstein in Zurich, Switzerland.

Kendall's research on cortisone is related to the original work by Thomas Addison (1793–1860) of Scotland who in 1849 discovered a connection between the adrenal glands and a rare disease that later became known as Addison's disease (an insufficient secretion of hormones by the adrenal cortex). This discovery encouraged a number of medical researchers to further examine the secretions from this gland that is located near the kidneys. This new secretion was called the hormone "cortin." Further experimentation by Kendall in the 1930s led to the identification of more complex secretions. Four of these hormone compounds were named A, B, E, and F; other substances were found later in adrenal secretions. It was also determined that the adrenal secretion cortin was a steroid. Steroids are naturally occurring lipids (fatty components of living cells) that are derived from cholesterol produced by the body. In 1948 Kendall produced a few grams of the compound E, and with the assistance of Dr. Philip S. Hench (1896–1965), his colleague and fellow researcher at the Mayo Foundation, he used it to treat patients with rheumatoid arthritis. It then became known as a "wonder drug" and was renamed "cortisone" in 1949.

Cortisone and related forms of adrenal secretions can be artificially produced and used to treat (but not cure) a number of ailments, particularly those of an inflammatory nature, such as asthma and arthritis. This is somewhat similar to the use of insulin to treat patients with diabetes because both drugs must be taken daily to maximize the therapeutic effect. Many diseases are successfully treated with the use of cortisone and other steroids that have saved lives and mitigated the suffering of patients. Some examples are rheumatic and endocrine disorders; dermatological, collagen, and neoplastic diseases; allergic, edematous, and gastrointestinal diseases; and tuberculosis. Cortisone is also used when performing organ transplants to minimize the body's defense mechanisms to foreign substances in the implanted organ. Some of the possible side effects of using cortisone as well as some steroids are depression and other psychic disorders including physiological and/or personality changes, insomnia, mood swings, and possibly the development of glaucoma.

See also Reichstein

KEPLER'S THREE LAWS OF PLANETARY MOTION: Astronomy: *Johannes Kepler* (1571–1630), Germany.

Law I: *All the planets revolve around the sun in elliptical paths, and the sun occupies one of the two focal points for the ellipse (the other focal point is imaginary).*

Kepler's mathematical analysis of Tycho Brahe's data resulted in the concept of planetary orbits as being ovoid (egg shaped). However, after checking his data, he corrected an error in calculation and realized that all planetary orbits, including the orbit of Mars, are elliptical.

Law II: *An imaginary straight line joining the sun and a planet sweeps over equal areas in equal intervals of time.*

Kepler's second law follows directly from the first law. Also referred to as the law of areas, it is probably the most important and easiest to understand. Kepler measured the distance of a short path of a planet progressing along a segment of its elliptical perimeter. In addition, he measured the time elapsed for the planet to cover this short segment of its orbit. Using geometry, he determined the area for the pie-shaped wedge of space formed by the two sides of a triangle originating at the sun (the meeting point of these two lines), which extends to the perimeter. The area of this pie-shaped wedge was related to the distance covered by the planet along its elliptical perimeter in a given period of time. He then made similar measurements as the planet progressed to different segments (chords) of its orbit (*see* Figure K2). When the planet was at its closest to the sun, it traveled much faster in its orbit to cover an area equal to that area covered when it was farthest from the sun.

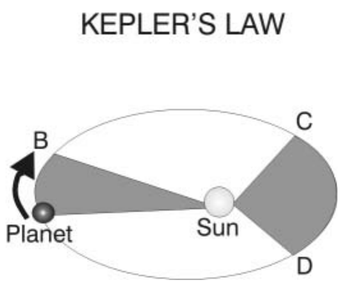


Figure K2. Kepler's second law states that planets revolve around the sun in an elliptical orbit and do so in a manner that equal areas are covered in equal times. (Figure not to scale.)

This law of areas was extremely important for Isaac Newton's formulation of his concept of gravity and his laws of motion. Kepler's second law also explains the theory for conservation of angular momentum for bodies in nonlinear motion. For instance, when an ice skater spins rapidly with arms extended and then pulls his or her arms in close to the body, increasing the rate of spin now conserves the momentum gained when the arms were extended. The same is true for an Earth-orbiting spacecraft. When it drops to a lower orbit, increasing its speed relative to the speed it had obtained in a higher orbit conserves its momentum.

Law III: *The square of planets' orbital periods is proportional to the cubes of the semi-major axes of their orbits.*

Another way to say this is that the square of the time it takes a planet to complete one orbit around the sun (orbital period) is proportional to the planet's average distance from the sun cubed. This may be expressed as: $P^2 = (AU)^3$, where *P* is the time it takes a planet to complete one revolution around the sun in years, and *AU* is the astronomical unit, which is equal to the average distance between Earth and sun, or about ninety-three million miles. Kepler developed his third law while attempting to devise a mathematical basis for musical-type harmony as related to his first two laws.

Kepler tried to apply mathematics to Plato's concept of five regular solids and from this derive mathematical harmony for Plato's model of the universe. He continued to apply his mathematics to achieve harmony with Copernicus' concept of a sun-centered solar system. After leaving his home in Germany, Kepler secured a position in Prague with Tycho Brahe, a firm proponent of Ptolemy's Earth-centered universe who never accepted the Copernican heliocentric theory. Tycho assigned his new assistant Kepler the task of observing and measuring the orbit of Mars. Kepler at first thought it would be a simple task, but it took him over eight years to complete it. Tycho died soon after Kepler joined his staff, leaving reams of data from his own extensive observations, which Kepler put to good use. Many historians give Tycho, not Kepler, credit for discovering that Mars' orbit is elliptical because this discovery was partly due to Tycho's sizable records that aided Kepler's accomplishment. This work led to Johannes Kepler's three laws of planetary motion, which remain valid.

> Kepler's laws have applications far beyond the orbits of planets. They apply to all kinds of bodies found in the universe that are influenced by gravity: moons orbiting their mother planets, other solar systems, binary stars, and artificial satellites orbiting Earth, for example. Kepler was also interested in other sciences beside astronomy. From his study of optics and vision, he developed a theory stating that light from a luminous body is projected in all directions, but when the human eye viewed this light, only the rays that enter the pupil of the eye were refracted, ending up as points on the retina. This is much closer to today's concept of electromagnetic radiation as related to vision than the ancient Greek idea of the eye sending out a signal to the object, which was then reflected back to the eye. After Galileo developed his telescopes, Kepler explained how the lenses of the instruments worked. He did the same for the new eyeglass spectacles. He was very supportive and complimentary of Galileo's work, even when others ridiculed Galileo's observations. It seems Galileo either did not understand or appreciate Kepler's mathematical contributions to astronomy because Galileo ignored his publications.

See also Brahe; Galileo; Newton

KERR'S THEORY OF QUADRATIC ELECTRO-OPTIC EFFECT (I.E., KERR EFFECT): Physics: *John Kerr* (1824–1907), Scotland.

As the electric field slowly varies with the voltage across a material, the material becomes birefringent at different indexes of refraction.

The Kerr effect, also know as the "quadratic electro-optical effect" or QEO, is a change in the refractive index of a material in response to an electric field, also known as **birefringence**. A more complete definition of the Kerr effect is the nonlinear interactions of a light beam within a medium (transparent solid or liquid) with an instantaneous response as related to the nonlinear electronic polarization.

The QEO theory can be expressed by a series of complex equations for linear and nonlinear relationships where the polarization varies with the electric field involved. Different equations are derived for different types of materials, including nonsymmetric media, such as liquids, where the refractive index is changed in the direction of the electric current. For instance, some liquids such as nitrobenzene ($C_6H_5NO_5$) have large Kerr constants that are exhibited by a glass cell (jar) containing these types of liquids. It is called a Kerr cell and is used to modulate light by quickly responding to changes in an electric field. Some applications of the Kerr cell are to measure the speed of a beam of light and for use with super-high-speed camera shutters. The Kerr effect can determine the change in the reflective index of an electric field that is the variation in the index of refraction, which is proportional to the local irradiance of the light beam. This effect is greatest when associated with very intense laser light beams. The Kerr effect can accomplish the same on magnetic fields, which is called the "magneto-optic effect."

KERST'S THEORY FOR ACCELERATING NUCLEAR PARTICLES: Physics: *Donald William Kerst* (1911–1993), United States.

> *Using a process for "stacking beams" by means of radio frequencies, it is possible to achieve center-of-mass energies through the use of colliding beams, thus greatly increasing the Me-V energies of accelerated particles.*

In 1929 John Cockcroft and Ernest T.S. Walton constructed a low-energy linear-type of "atom smasher" that used a voltage multiplier to build up a voltage high enough to accelerate alpha particles beyond the speeds they naturally obtained from radiation. These early linear accelerators built in a straight line did not provide the accelerated ions (charged particles) the energy required to enable them to smash into the nuclei of atoms to produce smaller subnuclear particles for study.

Dissatisfied with the low energies of particles achieved in the straight-line accelerators, Ernest O. Lawrence produced a design for a new type of accelerator. He believed that if the charged particles could be made to follow a circular path in a spiral, they could be influenced by a strong magnet during each path at every revolution. This "kick" at the beginning of each revolution would increase their speed and thus the energies necessary to interact with heavy nuclei of atoms. Lawrence's idea for a circular particle accelerator was based on the theory that the "bullet" particles, such as electrons, positrons, or heavier beta ions, could be continually pushed around the circular path building up to very high speeds, resulting in electron volts (eV) adequate to "smash" the nuclei of atoms. He constructed a small device with two "D" shaped semicircular units facing each other with a four-inch gap between them. This formed a circular unit he called a "cyclotron (*see* Figure F3).

Applying high-frequency fields to particles that have a charge (ions) will send them round-and-round in the two Ds. Thus, particles receive a "push" every time they pass the gap and reach very high energies as they follow the circular path formed by the two Ds.

While a professor at the University of Illinois in 1940, Donald Kerst developed the "betatron" to provide beams of electrons that exhibited much higher energy than the particles could achieve in the cyclotron. To increase the speed (and thus energy) of electrons to almost the speed of light, Kerst designed a torus-shaped (semicircular convex)

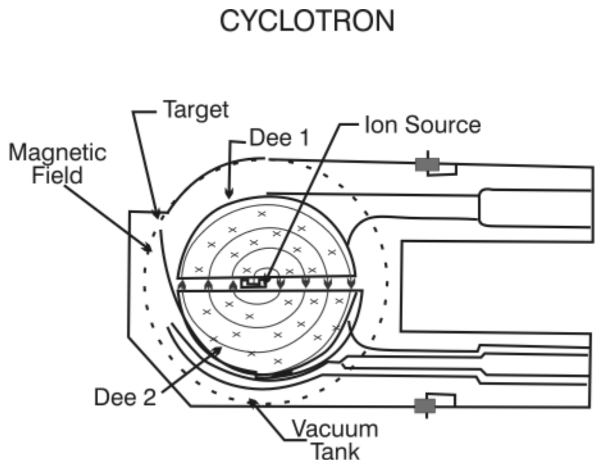


Figure K3. The cyclotron is a circular particle accelerator that was designed by E. O. Lawrence. It was based on the concept of two "D" shaped rings that could bring the particles to very high energies.

vacuum tube that was associated with a transformer. Because the mass of all particles increases at relativistic speeds as they approach the speed of light, they become extremely massive—meaning that particles with mass can never reach the speed of light because they would become infinitely heavier. Therefore, it requires great energies to accelerate particles to near the speed of light. Cyclotrons became less efficient as they could only generate energies of a few electron volts (eV). However, by the 1950s the betatrons could generate over 310 MeV. At these levels high-energy beams of electrons, when directed at metal plates, produce X-rays and gamma rays that are useful in industrial and medical applications, such as radiation for cancer treatment. Today, the next generation of accelerators, called synchrotrons, achieve even higher MeVs to explore the basic nature of particles. Other more powerful particle accelerators are planned.

Donald Kerst was a widely recognized and honored physicist who held many honorary degrees and awards. He began his academic career in the Midwest at the Universities of Illinois and Wisconsin in the late 1930s. During World War II he worked at Los Alamos, New Mexico, from 1943 to 1945. Colleagues remember him as an influential, hard-working researcher whose development of the betatron was only one of the contributions he made to the field of nuclear physics.

See also Higgs; Lawrence; Van de Graaff

KHORANA'S THEORY OF ARTIFICIAL GENES: Biochemistry: *Har Gobind Khorana* (1922–), India, United States. H. Gobind Khorana shared the 1968 Nobel Prize in Physiology or Medicine with Robert W. Holley and Marshall Warren Nirenberg.

> *There is a biological language code common to all living organisms that is spelled out in three-letter words, and each set of three nucleotides is a code for a specific amino acid which can also be produced artificially.*

Har Gobind Khorana was born in West Punjab (now in Pakistan) and educated in Indian schools and universities. In 1945 he entered the University of Liverpool in England where he received his PhD in 1948. After a brief time in India in the fall of 1949, he returned to England and the University of Cambridge where he became interested in research involving proteins and nucleic acids. In 1960 he moved to the University of Wisconsin where he started his work on understanding and possibly unraveling the genetic code. By combining different methods of analysis Khorana was able to overcome many obstacles to the chemical synthesis of polyribonucleotides. He proved that **codons** are triplets of mRNA (messenger RNA) that carry codes for each amino acid.

He synthesized each of the sixty-four nucleotide triplets that make up the code. This meant that three nucleotides specify an amino acid that determines the direction in which the information in messenger RNA can be read and that these codons (trinucleotide sequences) do not overlap. This also demonstrated that RNA is involved in translating the sequence of nucleotides in DNA into the sequences for the amino acids that make up proteins. Dr. Khorana's research added to the work already done in this field by American biochemists Marshall Nirenberg (1927–) at the National Institutes of Health and Robert Holley (1922–1993) at Cornell University and the Salk Institute in La Jolla, California. All three shared in the 1968 Nobel Prize for Physiology or Medicine.

This work with the genetic code led to Khorana's major achievement in 1970 when he synthesized oligonucleotides (strings of nucleotides), that is, the first artificial gene. After moving to the Massachusetts Institute of Technology he announced in 1976 the invention of a second artificial gene that was capable of living and operating in other living cells. This discovery opened the doors for research in various areas involving genetics. One possibility of practical use is in developing a cure for hereditary (genetic) diseases and artificially producing a source of proteins such as insulin.

See also Crick; Franklin (Rosalind); Pauling; Watson (James)

KIMURA'S NEO-DARWINIAN THEORY FOR MUTATIONS: Biology: *Motoo Kimura* (1924–1994), Japan.

> *Genetic mutations at the molecular level can increase within a population without being affected by Darwinian natural selection.*

Motoo Kimura developed data indicating there are certain types of mutations that multiply in a given population without resulting in these mutations being selected out, as proposed by Darwin's concept of natural selection. By using chemical means, he identified several molecules for mutant genes that proved not to be harmful to the individual. In fact, some of these seemed to adapt better than nonmutated genes. He concluded that evolutionary changes might be caused by a normal drift of selected genes that may have mutated. There is recent evidence of exceptions to his theory, which is based on findings that several mutations at the molecular level are selective (not random) and do cause evolutionary changes. One exception is the mutated gene affecting human hemoglobin in the blood. Another is the genetic decoding study conducted for the population of Iceland. Over the centuries, Icelanders were isolated and their numbers often reduced by natural disasters. Recent researchers found that an ancient survivor carried a mutated gene that was missing five units of DNA. The researchers concluded that the 275,000 modern Icelanders are somewhat inbred, as evidenced by similar characteristics (blue eyes, blond hair). Fortunately, Icelanders have maintained excellent genealogical and health records, which assisted in this genetic research. The descendants of this one person, who now compose a large portion of the present population, carry this mutation, which causes a high risk of breast cancer for men and women. This seems to be an example of a mutated gene at the molecular level that has drifted and was selected according to evolutionary theory, thus disproving Kimura's theory.

See also Darwin; Haldane

KIMURA'S THEORY FOR VARIATIONS IN EARTH'S LATITUDES: Astronomy: *Hisashi Kimura* (1870–1943), Japan.

Slight differences in latitudes at different geographic locations are due to an uneven distribution of mass around Earth's axis.

In 1765 Leonhard Euler observed that there were slight variations in **latitude** measurements at different geographic locations on Earth, but he had no understanding of why this might be so.

Hisashi Kimura spent his career as an astronomer studying and measuring the variations in Earth's latitudes. He was the director of the International Latitude Observatory in Mizusawa, Japan, that became one of the six observatories selected by the International Geodetic Association in 1899 for the study of latitudes around the world on a line of 39°08′ North. Kimura knew that a perfect symmetrical sphere with an even distribution of internal mass would have a stable spin. But it was also known for some years that Earth's mass is not distributed evenly around its axis. There are variations on both its surface and internally of quantities of mass at various geographic locations. Therefore, Earth is not symmetrical, and the axis of rotation and the axis of the moment of inertia do not match up. This discrepancy results in a slight wobble with a periodicity of about 14 months. However, the distance is small, and over this fourteen-month period Earth's poles drift about 63 feet (this spin is somewhat like the wobble of a child's top as it spins). This wobble is known as "**precession**" and was first discovered in 1891 by American astronomer Seth Carlo Chandler, Jr. (1846–1913). Today it is known as the "Chandler wobble." This precession is evident as Earth wobbles and its axis sweeps in a cone-shaped path at the poles. It takes about twenty-six thousand years to complete one cycle. In the year 2100 Earth's axis will point toward the star Polaris and then change its direction and thirteen thousand years later (one-half the twenty-six thousand period), the axis will point to the star Vega (*see* Figure K4).

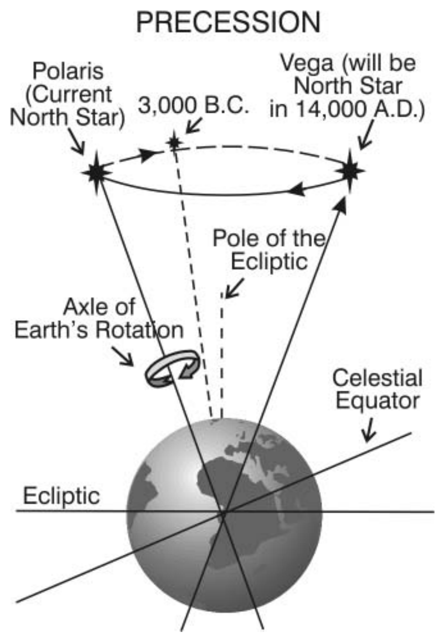


Figure K4. Since the Earth's axis of rotation and the axis of the moment of inertia are not the same, and the Earth's mass is not evenly distributed around its axis, the amounts of mass are not the same at various geographic locations. This results in a slight wobble (precession), both short term and over thousands of years.

The six observatories in the latitude study compared their latitude measurements at their locations and found discrepancies in latitudes of the six different observatories due to motion of Earth's poles. In 1902 Kimura also came up with a new term to describe some of these differences in latitude that was not dependent on precession. More recently this phenomena has been considered as one of the possible natural variables influencing climate change and the slight global warming (average about 1°C over the last century) of Earth due to changes in the direction of Earth's axis over long periods of time and also possibly due to natural phases of the sun's output of heat, as well as possible effects of modern civilization.

See also Euler

KIPPING'S THEORY OF INORGANIC-ORGANIC CHEMISTRY: Chemistry: *Frederick Stanley Kipping* (1863–1949), England.

It is possible to form organic compounds with interactions of inorganic elements.

Born and educated in Manchester, England, Frederick Kipping left England in 1885 and entered Munich University in Germany where he received his PhD in 1887, thus began a forty-year career studying organo-silicon compounds.

At the beginning of the twentieth century many chemists, including Kipping, experimented with combining a variety of inorganic elements with silicon to form simple molecules such as SiH_4, $SiCl_4$, $SiFl_4$, $SiBr_4$, and SiI_4. Because these compounds are very reactive, they were used to combine other elements including metals to form *organometallic* compounds such as diethyl-zinc and diphenyl-mercury. These types of compounds are referred to as *organic silanes* that do not react with water and are very inert and resist chemical change and withstand high temperatures. The production of chemicals, such as chlorofluorocarbons used to produce Freon and related refrigerants, have been reduced due to their stability and possible long-term effects on the ozone layer in Earth's atmosphere.

One theory for the origin of organic molecules is that inorganic elements and compounds, such as hydrogen, water, oxygen, methane (CH_4), and ammonia (NH_3) found in the atmosphere of early Earth mixed with rainwater and reacted, forming simple organic molecules that in some way replicated. Silicon is the second most abundant element on Earth (oxygen is the first). Silicon is considered an inorganic element and is a major element in the formation of rocks and sand. The atom of silicon is somewhat similar in the shape, as well as the chemical and physical properties, to the carbon atom in that both have a valence of 4 with the bonds forming a tetrahedron (*see* Figure V3 under Van't Hoff). Today organic chemical compounds all contain the element carbon, whereas carbon itself is considered a unique inorganic element because of its natural atomic structure that is capable of forming many different large molecular compounds with other inorganic elements that make up living tissue and the products of living plants and animals. In other words, organic chemistry may be defined as carbon chemistry. If one looks at the **Periodic Table of Chemical Elements**, carbon is located at the top of the Group 4 elements (indicating four valence electrons). Silicon is located just below carbon in Group 4, indicating that silicon has many similar characteristics and attributes of carbon, including four valence electrons and the tetrahedron structure. The atoms of both of these two elements are capable of forming compounds with the atoms of many other elements. Following are two examples of simple silicon molecules:

```
           Cl   Cl
             \ /
SiCl4 =      Si                SiO2 =  O=Si=O
             / \
           Cl   Cl
```

Carbon in particular can form thousands of compounds with other inorganic atoms (mainly hydrogen) to form long chains and ring structures of organic molecules that make up proteins, and so forth, of living plant and animal organisms, including the pricey "organic" vegetables, fruits, and meats marketed today. The term "organic" as used for these products is a misnomer because some of the molecules found in all food contain atoms of carbon, and thus all foods, no matter how they are raised, are organic (except for some seasonings such as some salts and vitamins). When the majority of other atoms that share valence bonds with carbon are hydrogen atoms, hydrocarbons are formed. There are also many other types of carbon molecules, most of which, but not all, are organic molecules. Examples of nonorganic carbon molecules are cyanide (CN) and carbon dioxide (CO_2).

Although each silicon atom has four valence electrons, only two of these are used to combine with an oxygen atom, which has two valence electrons. Silicon can bond with many other types of atoms to form a large group of what are known as "inorganic/organic silicones." These silicones are used in the manufacture of synthetic silicon-type rubber, plastics, high-temperature silicon greases, spray lubricants, hydraulic fluids that can withstand high temperatures, water repellants, and many other related products. Despite his four decades of work and research on organo-silicons, Kipping was unable to appreciate the commercial uses for his discoveries.

See also Kekule; Pauling

KIRCHHOFF'S LAWS AND THEORIES: Physics: *Gustav Robert Kirchhoff* (1824–1887), Germany.

Kirchhoff's electrical current and voltage laws: *1) The sum of all the current flowing in the direction of a point is equal to the sum of all the currents flowing away from that point,* $\Sigma\ 1 = 0$. *2) At any given time the algebraic sum of a voltage increase through a closed network loop will be equal to the algebraic sum of any voltage drop,* $\Sigma\ IR = \Sigma\ V$.

These two laws are important in the analysis of electrical circuits and for solving problems related to complex electrical networks. They are extensions to Ohm's law (*see also* Ampère; Ohm).

Kirchhoff's law of radiation: *A hot body in equilibrium radiates energy at a rate equal to the rate that it absorbs energy. Both the absorbed and radiated energy have the same given wavelength (black body radiation).*

Gustav Kirchhoff's law of radiation states that a perfect black body will absorb all light and other forms of radiation that are not reflected. A black body may be thought of as the perfect radiator where the maximum energy obtained per unit of time is due to the temperature of the "radiator." A radiator that is a perfect absorber is also a perfect reflector. Such a device is never found in nature. When heated, black bodies emit all the different wavelengths of light. This raised the question of how the different wavelengths of light were actually given off and how the individual wavelengths changed with temperature. Important theories related to energy, in particular, the visible light spectra followed, which led to the unification theory of electricity, magnetism, and light, referred to as the *electromagnetic spectrum*. The concept of black-body radiation also provided Max Planck the idea needed to develop his "quanta" theory (*see also* Maxwell; Planck).

Kirchhoff's theory for the use of the light spectrum in chemical analysis: *Each chemical element, when heated, exhibits a different line or set of lines in the spectrum of visible light.*

Sir Isaac Newton was the first to use a glass prism to split white light from the sun into a spectrum of colored lights. The English chemist and physicist William Hyde Wollaston, using an improved prism, divided these colors into seven distinct divisions (*see* Figure F8). Fraunhofer developed a "diffraction grating" made of fine wires to substitute for a glass prism, which enabled him to detect almost six hundred individual lines in the sun's spectrum. These devices made it possible for Kirchhoff to identify specific lines in the spectra of elements, thus identifying them by their particular colored light patterns. Kirchhoff and Robert Bunsen collaborated in the development of the spectroscope, which used the diffraction grating developed by Fraunhofer. The spectroscope consisted of a tube with a thin vertical slit on the front end, followed by a light-collecting lens and either a prism or diffraction grating. An eyepiece lens for viewing the specimen was located at the other end of the tube-shaped spectroscope. A small sample of the element to be analyzed was heated on a glass bead by Bunsen's new type of gas burner, which produced a flame hotter than an alcohol burner. When viewed through the slit/prism, or later through an improved diffraction grating, the light separated into specific spectra lines, unique for each element. These lines were then measured on a scale. Later, photographic plates were used that produced spectrophotographs for chemical analysis. By using this method Kirchhoff and Bunsen discovered two new metals: cesium and rubidium. The viewed image of lines of a specific element could be a bright spectrum, thus showing the element's spectrum as bright lines. Conversely, if the light from the heated element (including sunlight) was passed through a gas similar in wavelength to the element's wavelength, a dark line spectrum was visible. Spectroanalysis now can be used for analyzing the electromagnetic spectrum beyond the range of visible light, in the infrared and ultraviolet ranges, as well as X-rays from outer space. The technique has been invaluable in the analysis of the chemical makeup of all types of objects in the universe (e.g., the chemical composition of the sun and other stars, as well as the atmospheric composition of the planets). Today, spectroanalysis of the electromagnetic waves (radiation) given off by heated elements is an important analytical tool used by all fields of science.

See also Bunsen; Fraunhofer; Maxwell

KIRKWOOD'S ASTEROID GAP THEORY: Astronomy: *Daniel Kirkwood* (1814–1895), United States.

> *The asteroids located between the orbits of Mars and Jupiter are separated by gaps that correspond to their orbital periods and are integer fractions of Jupiter's orbital period.*

From the days of Galileo, chunks of matter smaller than planets yet large enough to be seen with a telescope were found in the region between Mars and Jupiter. It is estimated that over one hundred thousand objects, ranging from less than one mile in diameter to over 500 miles in diameter are located in this asteroid belt. About two hundred of these objects have been given names. These near-Earth bodies are called meteors and asteroids, whereas other bodies known as comets may spend some time in this asteroid belt. They usually are located at a greater distance from the sun. Comets have very large elliptical orbits, and some have paths that bring the comet's body closer to Earth than do the other objects in the asteroid belt. All of these objects are smaller than planets. Although asteroids are generally considered larger than meteors, both could cause great damage if they impacted Earth. The smallest meteoroids are about the size of a grain of sand, and when entering Earth's atmosphere at great speeds, they are heated to the point of incandescence thus producing a flash across the sky. When

Earth passes through a large number of these tiny meteors, a meteor shower is produced. When a small chunk of a meteor lands on Earth, it is called a meteorite.

Daniel Kirkwood detected a tugging on these asteroids/meteors by Jupiter's great gravitational force. This force created a resonance phenomenon (reverberation) in the smaller orbiting bodies. Asteroids that were drifting randomly were then pulled toward this region between Mars and Jupiter, thus forming their own orbits around the sun (*see* Figure K5).

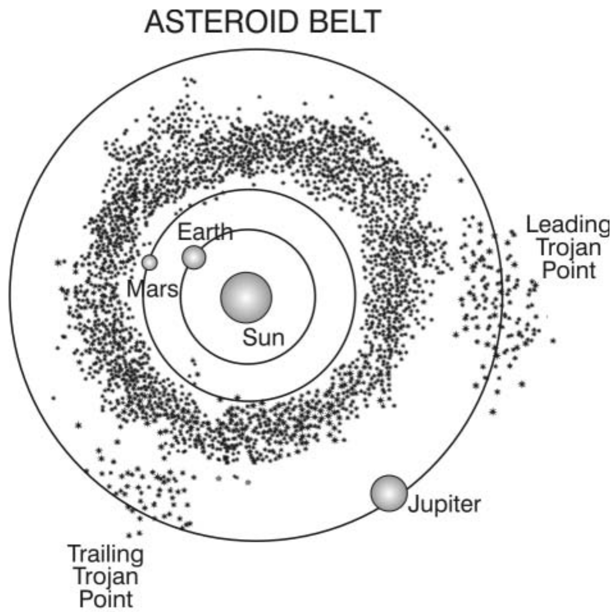


Figure K5. The diagram depicts the asteroid belt located between the orbits of Mars and Jupiter. Asteroids are leftover matter from the formation of the solar system and are too small to be considered planets. Jupiter's greater gravity most likely prevented them from coalescing into larger planets. This region is the source of most of the meteors and asteroids that intersect Earth's orbit.

This resulted in gaps among the thousands of asteroids revolving around the sun that appear as a number of "bands" void of asteroids. Kirkwood attributed this gap in the "rings" of asteroids to the influence of Jupiter's uneven gravity. The areas of depleted asteroids are called the "Kirkwood gaps" and are the consequence of their orbital separations related to their resonance motions with Jupiter. Kirkwood stated that asteroids in this gap would be forced into other orbits by perturbations caused by the bulge in Jupiter's shape, resulting in an uneven mass causing an uneven gravitational effect on the asteroids. Kirkwood also explained a similar theory for the separation of the Cassini divisions between the rings of Saturn. These divisions or separations between the rings of Saturn are partially caused by its moon, Mimas. The inner rings for the asteroid belt and Saturn's rings follow Kepler's laws of planetary motion. Because the inner sections of the ring must travel faster than the outer sections, density waves or ripples are formed that are called the *spiral density waves*.

See also Cassini; Kepler; Kuiper; Oort

KLITZING'S THEORY FOR THE QUANTIZATION OF THE HALL EFFECT: Physics: *Klaus von Klitzing* (1943–), Germany. Von Klitzing was awarded the 1985 Nobel Prize in Physics.

> *"Hall's resistance" resulting from a two-dimensional electron gas at very low temperatures is a continuous linear function of an applied magnetic field, but it can be measured in quantized steps by varying the steps in the applied magnetic field.*

Edwin Hall was the first to note that when an electric current is flowing in a conductor, it is influenced by a magnetic field that is located perpendicular to the surface

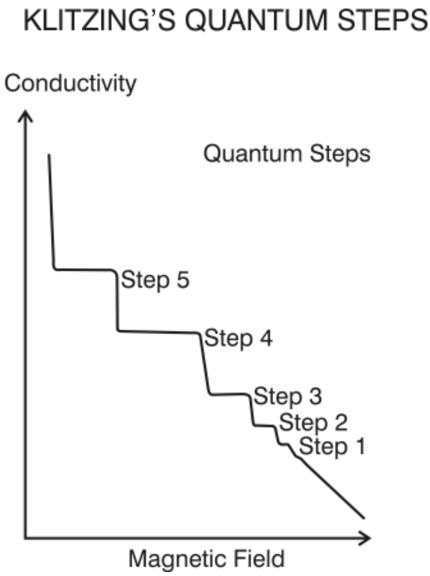


Figure K6. The tiny quantum changes in the ratio between the resistance of electrical flow and strength of a magnetic field was more of a small step-wise change than a continuous linear function.

of the conductor and produces what is known as the "Hall voltage." Hall voltage is at right angles to the direction in which the current flows and also the direction of the magnetic field. Thus, *Hall resistance* is determined by dividing the Hall voltage by its current (R = V/I). When measured and graphed, Hall resistance is linear in nature when it is influenced by a magnetic field.

The German physicist Klaus von Klitzing found that as the strength of the magnetic filed was increased, so did the Hall resistance in a linear manner, up to a certain point. It then leveled off. As the magnetic field was further increased, the Hall resistance would also increase and again level off, and so forth, which resulted in stepwise increases, rather than as a linear function (*see* Figure K6).

Klitzing devised an experiment to analyze this phenomenon. He used a very thin sheet of silicon to limit the movements of electrons to just two dimensions rather than three as normally occurs. Additional experiments were conducted using very powerful magnets kept at near absolute zero temperatures to verify the results. This setup demonstrated that the Hall effect becomes quantized as the changes in the magnetic field induced electrical changes in the silicon, only in certain distinct steps, thus not as a linear function. The result was that Klitzing discovered that the quantum steps had a value that proved to be a fundamental constant divided by an integer number. The National Institute of Standards and Technology Reference on Constants recognized Klitzing's constant as 25812.807449(86) ohms. Klitzing's discovery is extremely important to the physics community and is one of the few examples of the quantum effect being directly observed in a laboratory. He was recognized for this accomplishment with the 1985 Nobel Prize. The discovery of the quantized Hall effect gave a boost to the study of particle physics as well as providing a more precise meaning to the concept of ohms (electrical resistance).

See also Hall; Ohm; Planck

KOCH'S GERM-DISEASE POSTULATE: Biology: *Heinrich Hermann Robert Koch* (1843–1910), Germany. Robert Koch was awarded the 1905 Nobel Prize for Physiology or Medicine.

> *A set of specific conditions must be met before it can be established that a specific germ has caused a specific disease.*

Robert Koch arrived at his postulate after many years of trying to isolate and identify specific bacteria that caused a great variety of diseases for which there was no known cause or effective cure. These included anthrax, tuberculosis, sleeping sickness, bubonic plague, malaria, cholera, and other "germ-caused" diseases. He developed techniques for growing and isolating bacteria in **agar** cultures, staining them for identification and using inoculations to test the suspected germs. His methods and postulate are responsible for bacteriology's becoming a respected science.

Robert Koch's postulate states:

1. *The bacteria (germ) must be found in all cases of the disease that have been examined.*
2. *The bacteria causing the disease must be prepared, cultured, isolated, and maintained in a pure culture that has not been contaminated by other organisms.*
3. *Bacteria grown for several generations removed from the original specimen must still be able to produce the same infection (disease).*

Koch's most famous application of his postulate was his culturing, identifying, and maintaining the rod-shaped bacillus responsible for tuberculosis, a widespread disease that killed hundreds of thousands of people in Europe and Asia. Isolating this particular bacterium was difficult because it was so much smaller than others with which he had previously worked. Koch spent most of his life traveling the world in an attempt to identify the causes of and develop eventual cures for a number of diseases.

See also Pasteur

KOHLRAUSCH'S LAW FOR THE INDEPENDENT MIGRATION OF IONS: Physics: *Friedrich Wilhelm Georg Kohlrausch* (1840–1910), Germany.

> *The electrical conductivity of ions in a solution increases as the dilution of the solute increases in the solvent.*

Definitions for some terms follow:

- *Electrical conduction* is the passage of electrons or ionized atoms through a medium that in itself is not affected (wires, solutions, etc.)
- *Ions* are atoms or molecules that contain positive or negative charges.
- A *solution* is a mixture composed of two parts: the *solvent* (usually a fluid that effects the dissolving) and the *solute* (usually a soluble solid, such as sugar or salt—an electrolyte.
- *Electrolytes* are chemicals that, when molten or dissolved in a solvent, conduct an electric current.

Kohlrausch measured the electrical resistance of electrolytes, which are the dissolved substances that conduct electricity by transferring ions in solution. This means that when some substances, such as salt or acids, dissolve in water, an electric current can pass from the negative to the positive electrodes placed in the solution. The reason the current "flows" through the solution is that the electrolyte has formed ions (charged atoms) that carry the current. When direct current (**DC**) is used, there is polarization at the electrodes that interferes with the resistance of the current, thus making measurements difficult. To overcome this obstacle, Kohlrausch used alternating current (**AC**) instead of DC. This enabled him to measure accurately the conductivity of different electrolytes in solution. To some it may seem strange that the weaker the solution, the greater the flow of ions (current), but this is what Kohlrausch's law states. His theory is correct only over a limited range of dilutions because if the dilution increases to the extent that no ions are available in the solution, no electric current will be conducted between the electrodes (*see* Figure A7 under Arrhenius). In other words, absolutely pure water will not conduct electricity.

See also Arrhenius

KREBS CYCLE: Chemistry: *Sir Hans Adolph Krebs* (1900–1981), England. Sir Hans Adolf Krebs shared the 1953 Nobel Prize for Physiology or Medicine with Fritz Albert Lipmann.

> *All ingested foods undergo a chemical breakdown while going through a cyclic sequence of reactions where sugars are broken down into lactic acid, which is metabolized into citric and other acids and further oxidized into carbon dioxide and water, releasing a great deal of energy.*

The Krebs cycle, also known as the citric acid cycle or the tricarboxylic acid cycle, is a sequence of enzyme reactions involving the process of oxidation in the metabolism of food, resulting in release of energy, carbon dioxide, and water in the body (*see* Figure K7).

Prior to his work with the citric acid cycle, Hans Krebs worked with the German biochemist Kurt Henseleit (1907–1973) in 1932 on the Krebs–Henseleit Cycle, which is another cycle that occurs during the metabolism of food that supplies energy in animals. It is also known as the *urea cycle* where amino acids eliminate nitrogen from the body in the form of urea that is expelled from the body in the urine. The result was that the purified amino acids (which make up proteins) now provide energy to animals by other metabolic paths. This urea cycle and the Krebs citric acid cycle are responsible for the source of energy in animals that take in oxygen in the processes of respiration and the metabolism of digested food.

A number of scientists studied the metabolism of carbohydrates and the various forms of organic carbon molecules, but they were unsure as to how these chemical reactions all came together in living organisms. Food is first broken down into smaller carbon groups that combine with a four-carbon compound called citric acid. This citric acid molecule loses its carbon atoms, which frees up four electrons that produce energy in the form of

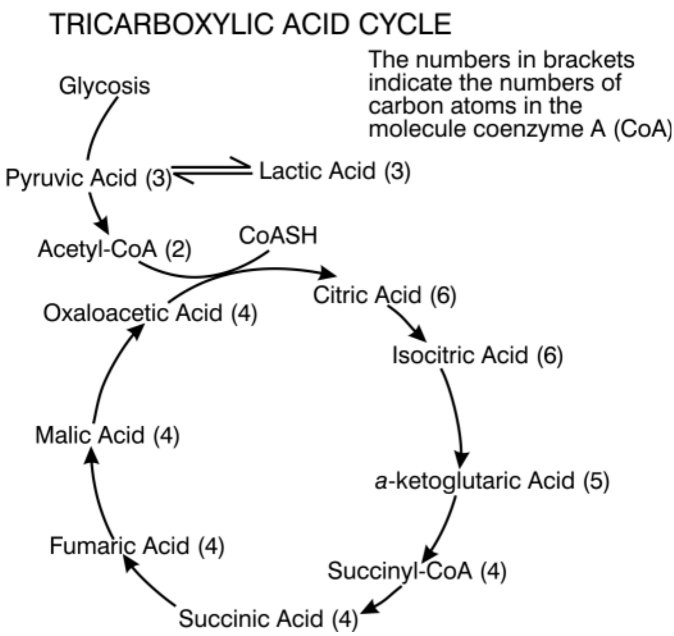


Figure K7. The Krebs cycle is also known as the Tricarboxylic Acid Cycle and is a sequence of oxidation processes involved in the metabolism of food resulting in the release of energy in the body.

adenosine triphosphate (ATP). Next, another energy-type molecule, guanosine triphosphate (GTP), is formed in the cycle. Still later in the cycle, the original molecules are regenerated and act as catalysts to start the whole cycle over again. Hans Krebs located two organic acids that contained six-carbon atoms, as well as other acids already known to contain five- and four-carbon atoms (*see* Figure K7). From this information he devised the cycle, with the carbon dioxide molecules exiting at the other end of the cycle. The process ends with the release of energy to the organism followed by an uptake of more carbohydrates (sugars), enabling the whole cycle to start all over again. Krebs was aware of the significance of this cycle of chemical reactions as the main path for the breakdown of all foods eaten by animals. This important process is both the source of energy for our living cells, as well as the process that is responsible for **biosynthesis**.

KROTO'S "BUCKYBALLS": Chemistry: *Harold Wiliam Kroto* (1939–), England. Harold Kroto, Richard E. Smalley, and Robert F. Curl shared the 1996 Nobel Prize in Chemistry for their discovery of fullerenes.

> *Graphite subjected to laser beams produces sixty carbon atoms bunched together in the form of a twenty-sided polyhedron.*

Harold Kroto collaborated with the American professor of chemistry, physics, and astronomy Richard E. Smalley (1943–2005) who used laser beams to vaporize metals that, when cooled, formed compact masses or groups of one-of-a-kind metallic atoms.

> Applied scientists and engineers, who study the chemical and physical nature of various materials and how these materials can be utilized in practical ways, are exploring some exciting avenues. In addition to macro and micro technologies that rely on materials of a relatively large scale, nanotechnology is a subclassification of technology in colloidal science, biology, physics, chemistry, and other fields that involve manipulations of materials at the nano level. This level is far smaller than micro, or even submicro levels. It deals with particles at the 10^{-9} size (one-billionth of a meter), which is at the size of molecular and atomic particles of matter. There are two types of nanotechnology—the bottom-up approach that builds up materials atom by atom and the top-down method where nano-size particles are removed from larger substances to form nano-sized materials. In the computer business new and faster chips that use macro materials are nearing the physical limits of their semiconducting materials. According to Moore's Law (stated in 1965 by Gordon Moore of Fairchild Semiconductors) the number of transistors that could be placed on a chip would double every eighteen months. This has been pretty much true over the past decades, but there are limits to this continued improvement, and those limits are physical limitations at the molecular and atomic levels. This is a challenge for technologists to make nano-sized computer circuits at the single molecule or atomic levels. At this nano level, there are indeterminacy problems related to the quantum behavior of particles, in other words, where a particle's position and momentum cannot be determined at the same time. There is great potential for nanotechnology, which has an exciting future, but there are a few dangers. One is the physical law: *the smaller the size of a particle the larger is its surface area compared to its volume*. This means that nano particles have different properties than normal-sized particles and could be harmful to living organisms, tissues, and cells. Such small particles can enter the body by swallowing or breathing; they are even small enough to pass through the pores of the skin. Nano particles may also be harmful to the environment. Further study still needs to be done in this exciting field as it promises more advantages than disadvantages in the future.

Kroto suggested graphite (a form of carbon) could be used to create new structures for groups of carbon atoms. Before finishing their research, they exhausted their research funds. A few years later, several other scientists repeated the experiment and produced an amount of material adequate for analyzing and verifying its structure. The result was a ball-like molecule that resembled a field soccer ball or a geodesic dome, similar to the ones designed by American architect Buckminster Fuller (*see* Figure C7 under Curl.) Thus, the C_{60} molecule was given the name *buckminsterfullerene* or, more commonly, "buckyballs." The unique sixty atoms, twenty-side polyhedron group of carbon molecules continues to be explored for properties that may improve the structure and functions of other materials. Since the discovery of C_{60}, other polyhedrons with more than sixty atoms have been produced experimentally. This discovery was the beginning of the material-sciences of *nanotechnology*.

See also Curl; Van't Hoff

KUIPER'S THEORY FOR THE ORIGIN OF THE PLANETS: Astronomy: *Gerard Peter Kuiper* (1905–1973), United States.

The planets evolved from condensing gas clouds distinct from the gas that formed the sun.

Gerard Kuiper discovered a new satellite for Uranus and another for Neptune. He also determined that carbon dioxide gas is present in the thin atmosphere of Mars and that Titan, the largest of Saturn's satellites, has an atmosphere composed of methane. Kuiper theorized some comets originated beyond the Oort cloud, at a distance of more than one hundred thousand AU (the AU is the unit used to measure distances in the solar system that is equal to the average distance between Earth and the sun. One AU equals approximately ninety-three million miles). He also postulated that the space beyond Pluto contains many comets with solar orbital periods of hundreds of years. In 1992 the first objects were found at about 120 to 125 AU in the Kuiper belt, thus verifying the theory he had advanced forty years earlier. All of these ideas relate to the formation of comets, asteroids, and planets from gas clouds. Like the planets, the objects in the Kuiper belt are primitive remnants left over from the formation of our solar system. Kuiper also theorized that some of our short-term comets originate in the Kuiper belt, whereas other long-term comets originate in the Oort cloud.

Kuiper proposed two other theories that are not generally accepted. One was his measurement of the planet Pluto. Based on his estimates of the perturbations of Pluto on Uranus, he estimated Pluto's size to be about half Earth's diameter (it later proved to be only about one-fourth Earth's diameter). Second, his estimate of the mass of Pluto was also much too large. These errors were later corrected. Other astronomers no longer accept Kuiper's theory that the planets formed from their own gaseous clouds. Before his death, Kuiper was involved in several of the early NASA space missions.

See also Oort

KUSCH'S THEORY FOR THE MAGNETIC MOMENT OF THE ELECTRON: Physics: *Polykarp Kusch* (1911–1993), United States. Polykarp Kusch shared the 1955 Nobel Prize for Physics with Willis Lamb.

The electron, like all other charged particles, will possess a magnetic moment (field) due to the motion of its electric charge.

Polykarp Kusch used the interacting principle of electromagnetism to demonstrate that the electron, which has an electrical charge, is affected by a magnetic field. His measurements, which were extremely accurate, were based on the structure of different energy levels of several elements. He discovered that all particles containing an electrical charge do exhibit a turning effect in a strong magnetic field. Later, it was determined that the neutron, which has zero electrical charge, will also be affected by a strong magnetic field due to its internal structure, which involves a polarity distribution of positive and negative charges (A neutron is basically composed of a negative electron and a positive proton, or it might be thought of as three quarks held together by gluons.) This polarity is why nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI) work. The magnetic field around the patient causes nuclei in the different tissues to resonate (oscillate at different rates) with the applied field and is thereby detected by the MRI instrument, producing an X-ray type image of the tissue. Kusch's work also led to the concept of quarks and the field of quantum electrodynamics.

See also Gell-Mann

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Robert E. Krebs

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LAGRANGE'S MATHEMATICAL THEOREMS: Mathematics: *Comte Joseph-Louis Lagrange* (1736–1813), France.

Lagrange's theory of algebraic equations: *Cubic and quartic equations can be solved algebraically without using geometry.*

Lagrange was able to solve cubic and quartic (fourth power) equations without the aid of geometry, but not fifth-degree (quintic) equations. Fifth-degree equations were studied for the next few decades before they were proved insoluble by algebraic means. Lagrange's work led to the theory of permutations and the concept that algebraic solutions for equations were related to group permutations (group theory). Lagrange's theory of equations provided the information that Niels Abel and others used to develop group theory (*see also* Abel; Euler; Fermat).

Lagrange's mechanical theory of solids and fluids: *Problems related to mechanics can be solved by nongeometric means.*

Before Lagrange, Newtonian mechanics were used to explain the way things worked, as well as to solve problems dealing with moving bodies and forces. By applying mathematical analyses to classical mechanics, Joseph-Louis Lagrange developed an analytical method for solving mechanical problems that used equations having a different form from Newton's law (F = ma), by which acceleration is proportional to the applied force to accelerate the mass. Lagrange's equations, which can be shown to be equivalent to Newton's law and can be derived from Hamilton's formulation, are, like Hamilton's formulation, very convenient for studying celestial mechanics. In fact, Lagrange himself applied his equations to the mechanical problems of the moon's **librations** (oscillating rotational movement), as well as those dealing with celestial mechanics. For one example, he solved the three-body problem when he demonstrated by mechanical analysis that asteroids tend to oscillate around a central point—now referred to as the *Lagrangian point* (*see also* Einstein; Newton).

Ancient people used the natural motions and cycles of the sun and moon, the seasons, and other natural observable phenomena to determine some of their measurements of time. Historically, many countries had their own system of weights and measurements that were arbitrarily based on someone's idea of how much or how long something should be. Movement of people from region to region made communication and trade difficult when different systems of measurements as well as languages meshed. The introduction of the metric system is an example of the need for some standardization of units of weights and measurement. For instance, the metric system grew out of the Age of Reason in Europe and was spread widely across nations as the advances of Napoleon's army introduced it. For example, this was the first time that kilometers rather than miles were used throughout Europe. It was natural for the United Sates to adopt the English systems of weights and measures since we were an English colony. Even so many enlightened leaders, such as Thomas Jefferson, Benjamin Franklin, John Quincy Adams, and others recognized the utility of the metric system (e.g., it is easy to convert weight to volume because 1 gram of water equals 1 milliliter or cubic centimeter of water). Jefferson developed his own decimal system that was somewhat like the metric system except he used his own terminology and units. For example, he based his system on a decimal system that did not equate different units. He declared that the foot was just 10 inches (somewhat shorter than the English foot); each inch was divided into ten lines, and each line into 10 points. Ten feet equaled a decade, 100 feet equaled a rod, 1,000 feet a furlong, and 10,000 feet equaled a mile (the present English mile is 5,280 feet long). But his decimal system of weights and volume was not based on some natural phenomena, as was the metric meter that was based on a fraction of the distance of the meridian that extended from the North Pole to the equator through a particular point in Paris, which was divided by 1/10,000,000. This distance was named *meter* after the Greek word for ''measure.'' Today the meter is defined as the length a path of light travels in one 299,792,458th on a second and is based on the speed of an electromagnetic light wave in a vacuum.

The history of the acceptance of the metric system in the United States is not pretty.

1. 1800—was one the first times that the metric system was used in the United States when the U.S. Coast Guard used the French standard of meters and kilograms in its Geodetic Survey.
2. 1866—Congress authorized the use of the metric system and supplied each state with weights and measures standards.
3. 1875—The Bureau of Weights and Measures was established and signed the Treaty of the Meter to use this standard.
4. 1893—The United States adopted the metric standards for length, mass, foot, pound, quart, as well as other metric units.
5. 1960—The Treaty of the Meter of 1875 was modernized and called the International System of Units (SI) as the metric system is known today.
6. 1965—Great Britain begins conversion to the metric system so they could become a member of the European Common Market.
7. 1968—U.S. Congress passes the Metric Study Act of 1968 to determine the feasibility of adopting the SI system.
8. 1975—U.S. Congress passes the ''Metric Conversion Act'' to plan the voluntary conversion to the SI system.
9. 1981—The Metric Board reports to Congress that it lacks authority to require a national conversion.
10. 1982—The Metric Board is abolished due to doubts about the commitments of the United States to convert.
11. 1988—U.S. Congress has introduced ''carrot'' incentives to U.S. industries to convert, and by the end of 1992 all federal agencies were required to use the SI system for procurements of grants, and so forth.

(*Continued*)

Today, there are both metric and English systems placed on commercial products (e.g., ounces and grams), but there is much opposition to changing transportation (road) signs to kilometers from miles. It seems the American public, despite years of learning the metric system in schools, still does not recognize or accept the utility of the SI metric system, and stubbornly adheres to the use of the archaic English system of weights and measures.

Lagrange's concept for the metric system: *A base ten system will standardize all measurements and further communications among nations.*

Historically, all nations devised and used their own system for measuring the size, weight, temperature, distance, and so forth of objects. As the countries of Europe developed and commerce among them became more common, it was obvious that the jumble of different measuring systems was not only annoying but limited prosperity. At about the time of the French Revolution, a commission was established to solve this problem. Lagrange, Lavoisier, and others were determined to find a natural, constant unit on which to base the system. They selected the distance from the North Pole to the equator as a line running through Paris. This distance was divided into equal lengths of 1/10,000,000, which they called a *meter* ("measure" in Greek). A platinum metal bar of this length was preserved in France as the standard unit of length. Today, a meter is defined as the length of the path light travels in one 299,792,458th of a second and is based on the speed of electromagnetic waves (light) in a vacuum. Units for other measurements besides length were devised, using the base of ten to multiply or divide the selected unit. For instance, a unit of mass is defined as the mass accelerated one meter per second by a one-kilogram force. After several years of resistance, other countries recognized the utility of the metric system, which has since been adopted by all countries, except the United States, Liberia, and Myanmar (formerly Burma). Even so, international trade and commerce have forced the United States to use the metric system along with the archaic English system of measures. Despite several attempts to convert the United States to the metric system, the general public has refused to accept it.

LAMARCK'S THEORIES OF EVOLUTION: Biology: *Jean Baptiste Pierre Antoine de Monet, Chevalier de Lamarck* (1744–1829), France.

Theory 1: *New or changed organs of an animal are the result of changes in its environmental factors.*

Lamarck proposed that the first requirements for modifying the form or structure of an organism were changes in environmental circumstances. This was the basis for his view that there was a natural tendency for greater complexity and that a change in the environment was responsible for the changes in functions and forms of the organs of animals. In other words, the occurrence of new organs in an animal's body is the result of some new need that became "felt" by the animal.

Theory 2: *Those parts of an animal not used will either not develop or will degenerate over time, and those parts of an animal that are used will continue to develop and change over time. The ''need'' responses by animals over many generations are acquired changes in functions and structures that will be inherited in future generations.*

Lamarck believed these changes resulted from environmental factors, which led to changes in the animals' behavior as well as structure, and, in time, this acquired behavior also become habitual. One of his examples was the behavior of antelopes fleeing from predators. As they ran faster, their leg muscles developed, thus passing this escaping behavior and fleetness to offspring. In other words, as the environment changes, so does an animal's behavior, as well as its organs' functions, and structure. The behavior becomes an active agent for the species' evolutionary development, and when this behavior becomes habitual behavior, it determines the extent and nature of the animal's structure. This is usually referred to as the *inheritance of acquired characteristics*, which includes an interpretation of the pre-Darwinian concept of natural selection. But this natural selection, according to Lamarck, resulted in either habitual use or disuse of a particular body part, which carries over from generation to generation. One of the classical examples of the inheritance of acquired characteristics is the theory of how the giraffe acquired its long neck. The giraffe had to stretch higher and higher to obtain tree leaves for food after the lower leaves were consumed. Thus, over time, the giraffes "acquired" longer and longer necks, a characteristic passed on to the next generations. Today, however, it is usually considered that possibly due to genetic mutations, some giraffes with slightly longer necks were able to secure more food, be healthier, live longer, and thus reproduce more giraffes with the altered genes.

Lamarck's ideas were not well received by other scientists, including Darwin. Even so, at one time Darwin accepted some aspects of the concept of acquired characteristics caused by environmental changes and incorporated this into his theory of natural selection.

See also Buffon; Cuvier; Darwin; Lysenko

LAMBERT'S THEORIES: Mathematics, Physics, and Astronomy: *Johann Heinrich Lambert* (1728–1777), Germany.

Johann Lambert was a multitalented scientist who made contributions to many branches of science and added to the knowledge of his day. Lambert's many theories and hypotheses in areas of physics and astronomy derived from his contributions to mathematics. Following is a short synopsis of some of his contributions to these fields.

In the field of optics the Lambert–Beer Law is also known as the *Beer–Lambert–Bouguer law* because three men contributed to this field (the law is named after Lambert, the German mathematician August Beer [1825–1863], and the French mathematician and astronomer Pierre Bouguer [1698–1758]). The law is based on an observable relationship between the absorption of light to the nature of the material through which the light is traveling. The law is a mathematical means of expressing the factors related to the absorption of light and is based on three physical phenomena:

1. The concentration of light through an absorbing medium is known as its "pathlength."
2. The optical "pathlength" (OPL) is the length to which the light must travel.
3. The *absorption coefficient* is the probability that a photon of a specific wavelength of light will be absorbed.

The connection between these factors can be expressed by the following equation: A = ϵdc, where A = absorption; ϵ = a coefficient; *d* = is the pathlength in centimeters; and *c* = the molar concentration.

For the *transmittance* of a beam of light passing through an absorbing medium, the amount of light absorbed is proportional to the light's intensity times the coefficient of the absorption medium. This relationship is expressed by one of Lambert's law of optics as expressed in the mathematical equation as follows:

T = 10 − ϵcd, where *T* = transmittance of the light; ϵ = the molar extinction coefficient; *c* = the molar concentration; and *d* = the pathlength in centimeters. Note: this equation can also be written as T = 10 − A, where -A is the same as (ϵ*cd*) the absorption of the light.

The *absorption* of the transmitted light can also be expressed as the strength of the incident radiation that can be plotted against the concentration of the light. Because this relationship is not linear, it is expressed as a negative log 10. It can be expressed as follows: A = −log 10 (T).

The Lambert–Beer law is also related to the atmosphere. It can be used to describe the diminishing of the radiation of sunlight as it travels through Earth's atmosphere. There is a scattering of the sun's radiation as well as absorption by the extent of aerosols (tiny particles and gases) in the atmosphere (*see* the Tyndall Effect).

Lambert made several contributions to the field of mathematics. In his studies of light intensities and absorption he introduced the hyperbolic functions into the field of trigonometry. He also coined the word "albedo" which is the reflection factor of light off a surface. He proved that pi (π) is an irrational number by the continued use of fractions. By using non-Euclidean geometry he devised theories related to conic sections as a means to calculate the orbits that comets follow. He theorized that the sun and its planets travel together through the Milky Way, and that there are many galaxies in the universe, such as the Milky Way, with many sun-like stars that have their own planetary systems.

Lambert was familiar with Kant's nebular theory that stated that the planets in the solar system originated from a gassy cloud, which was evidence of God's existence and wisdom. Sometime later, Lambert published his own version of the origin of the solar system that was not dependent on God's wisdom. He theorized that there were many galaxies beyond the Milky Way, and they all had planetary systems revolving around the many suns in each galaxy. Lambert was also a successful inventor and was given credit for inventing the first *hygrometer* and the first *photometer*, both in 1760. A hygrometer measures the relative atmospheric humidity, and the photometer measures the brightness of light also known as flux.

See also Kant; Newton

LAMB'S THEORY FOR THE QUANTUM STATES OF THE HYDROGEN ATOM: Physics: *Willis Eugene Lamb, Jr.* (1913–), United States. Willis Lamb shared the 1955 Nobel Prize for Physics with Polykarp Kusch.

Each of the known states of hydrogen is actually two states having the same energy in the absence of a magnetic field. However, the two states exhibit slightly different energies in the presence of a weak magnetic field.

Willis Lamb's theory on the quantum states of the hydrogen spectrum required a slight revision of Paul Dirac's electron theory, which stated, according to quantum mechanics, that the hydrogen spectrum should exhibit two different but equal states of energy. Lamb's research demonstrated that the spectrum of the hydrogen atom was split into two parts, but there was a small shift of the energy level of the hydrogen spectrum from that which Dirac predicted. This discrepancy for the predicted quantum electrodynamics of the hydrogen atom is now known as the *Lamb shift*. Willis Lamb first demonstrated it by splitting the spectrum for hydrogen into two distinct parts, each with slightly different energy states. His research revealed how electrons act within the influence of electromagnetic fields and is considered important for the electronics and computer industries in the development of new products.

See also Dirac; Kusch; Lorentz; Zeeman

LANDAU'S "TWO-FLUID MODEL" FOR HELIUM: Physics: *Lev Davidovich Landau* (1908–1968), Russia. Lev Landau was awarded the 1962 Nobel Prize for Physics for his work on condensed matter.

> *Depending on its temperature the gas helium exists in two different liquid states, "phonon" and "roton."*

Landau founded a major field of theoretical physics known as "condensed matter" in the mid-twentieth century. This is matter that exists as either a liquid or solid at a very low temperature even though it may be a gas at room temperatures. He used this theory to explain the unique behavior of helium gas at temperatures below about 2.17 kelvin (K) at which point it becomes a liquid. At near absolute zero temperatures below 2.17 K helium exhibits superconductivity and superfluidity where it will flow up the sides of a beaker and over the edges. He and other scientists named this form of helium below 2.17 K as "helium II" and named its particle a "phonon" which is a "quantum of thermal energy." For particles of helium above the critical 2.17 K temperatures they called it "helium I," which is the elementary quantum measurement of the motion of a vortex formed in a liquid. The point at which helium becomes superfluid is called the critical point (or Lambda point) which, when graphed, exhibits a jump in specific heat, and exhibits a discontinuity in its density. This is one area of theoretical physics that has been proven experimentally. This area of super cold and superconductivity research in physics was speeded up when room temperature helium-3 could be produced in fairly large amounts by nuclear reactors. Although helium-4 which is normal helium with two protons and two neutrons in its nuclei works well when supercooled in establishing helium's critical point, helium-3 with two protons and one neutron in its nuclei showed promise for studying vortex motions below the critical point. Helium-3 could be cooled down to just 2 mK, which is just a tiny fraction of a degree above absolute zero (K) or −273 C. This is one thousand times cooler than the critical point of 2.2 K for helium-4. 2 mK is the point at which helium-3 becomes a *superfluid*. At this temperature the helium atoms "paired" up to form very slow moving boson particles that exhibited Bose–Einstein qualities of superfluids. (Bose–Einstein refers to the gas-like qualities of electromagnetic radiation. It is named after Albert Einstein and the Indian mathematician and physicist Satyendra Nath Bose [1894–1974] who collaborated on this theory.)

After graduating from universities in Russia in the 1920s, Landau visited centers in Europe where problems in theoretical physics were being explored. One of these centers was in Copenhagen, Denmark, where he became lifelong friends with Niels Bohr. Upon returning to Russia he became head of several university physics departments. Landau is responsible for developing several well-known schools of theoretical physics. His accomplishments ranged in many fields of physics including quantum electrodynamics (QED), atomic and nuclear theories, particle physics, astrophysics, thermodynamics, electrodynamics, quantum mechanics, and low-temperature physics.

LANDAUER'S PRINCIPLE FOR VERY-LARGE-SCALE INTEGRATION: Physics: *Rolf Landauer* (1927–1999), Germany and United States.

Landauer's principle states, in essence: *Any irreversible computing of logical information must be accompanied by a corresponding increase in entropy as a dissipation of energy; thus there is an increase in noninformation.*

This principle is based on a consequence of the second law of thermodynamics that states that entropy in a closed environment will always increase and never decrease. This related to the development and advances in the number of transistors, etc., that can be integrated in a semiconductor chip. About sixty-five to seventy-five years ago the first practical computers used vacuum tubes to process data. These early room-sized computers required many heat-producing vacuum tubes that required giant air conditioning systems to keep them cool. Their computing power was also less than today's high-powered modern home computers. Single semiconductor chips soon replaced inefficient vacuum tubes. Several individual purpose circuits that were integrated into these single chips eventually followed. These were the first *small scale integration* (SSI) chips that contained several devices, such as diodes, transistors, resistors, and capacitors, on a single chip that made it possible to form more than one logic-gate on a single chip. The next generation of integrated chips was called *large-scale integration* (LSI) that contained about a thousand logic gates. *Very large-scale integration* (VLSI) chips that contained many thousands of logic functions on a single chip followed this generation. This nomenclature no longer makes sense because today there are semiconductor chips that provide many hundreds of millions of gates on a single chip. In a few years we will see the production of billion-transistor processors on a single chip that operate at just a few nanometer processes or at the molecular level of gates.

Rolf Landauer was born in 1927 in Stuttgart, Germany, and immigrated in 1938 to the United States at age eleven with his parents. He received his undergraduate degree at eighteen years of age from Harvard University and then served in the U.S. Navy. He earned his PhD from Harvard in 1950, after which he worked at IBM in Westchester County, New York. This is where he arrived at his principle that each bit of information lost in a computer circuit will result in the release of a specific amount of heat. However, it has since been determined that if there is no erasure of information it may be possible to reverse thermodynamics by not releasing heat. This has led computer scientists to develop the concept of reversible computing—which has yet to be realized.

See also Bardeen; Brattain; Shockley; Turing; von Neumann.

LANDSTEINER'S THEORIES OF BLOOD GROUPS: Biology: *Karl Landsteiner* (1868–1943), United States. Karl Landsteiner won the 1930 Nobel Prize for Medicine or Physiology.

> *Individuals within a species exhibit different proteins in their blood serum (plasma), just as different species also exhibit different blood groups.*

Since 1628 when William Harvey explained the circulatory system in animals, scientists and physicians were aware that blood from one animal species was incompatible with the blood from another animal species. When incompatible blood types are mixed during a transfusion, the blood will clot, blocking blood vessels, which leads to death. At the beginning of the twentieth century, Karl Landsteiner demonstrated that only blood serum from certain types of patients could be mixed with blood from others whose blood had some similar characteristics. He found that the plasma (liquid portion of the blood) from some human donors would form clots in transfusions for a person with A-type but not for a person with B-type blood. Thus, a person with A-type blood could provide blood that was safe for another person with A-type blood. He also found that some other types of blood were incompatible with a person with B-type blood, and that some types of blood would clot for both A- and B-type people, and blood from still other people would not clot either A- or B-type people. This resulted in the classification of blood into the four groups: A, B, O, and AB. Only people with O blood can donate to most people from the other groups, but only in an emergency; a definite match for the other types is required. The understanding of blood grouping has increased and has been used to determine parenthood long before DNA testing. Due to Landsteiner's efforts, blood transfusions are safe.

LANGEVIN'S CONCEPT FOR USE OF ULTRASOUND: Physics: *Paul Langevin* (1872–1946), France.

> *High frequency electrical currents can cause piezoelectric crystals to produce short ultrasound wavelengths mechanically.*

Paul Langevin built on the work completed by Marie and Pierre Curie as related to piezoelectric crystals. Pierre Curie realized that when a mechanical force was applied to a piezoelectric crystal, an electric current is generated between the two sides of the crystal. He used this process, in reverse, to measure the amount of radiation (strength) of the radioactive element on which he and Marie Curie were working. Langevin theorized that if a variable (alterable) electric current could be sent across one side of a crystal to the other side, the crystal would vibrate rapidly, thus producing sound waves shorter than those that can be heard by the human ear (e.g., ultrasound). He also was aware that sound waves of high frequency travel better under water than do light waves. Therefore, objects under water should be detectable at greater ranges using sound waves rather than light waves. His theory was later applied to the development of a system called echolocation, which during World War II became known by the acronym *sonar* (**SO**und **N**avigation **A**nd **R**anging). Sonar used ultrahigh frequency sound waves generated by the piezoelectric crystals to detect enemy submarines. Since then, sonar has been used as an invaluable tool in the field of oceanography. Not only can it detect objects, such as schools of fish and sunken ships, but it can also be used to measure the contour of the ocean's floor.

LANGLEY'S THEORIES OF THE NERVOUS SYSTEM: Physiology: *John Newport Langley* (1852–1925), England.

1. *The autonomic nervous system (ANS) is the part of the nervous system that controls **homeostasis** of the body.*

2. *There are specific sensors in the nervous system that act as receptors for specific types of drugs.*

John Langley coined the term "autonomic nervous system" (ANS) in 1898. This term includes the "sympathetic nervous system" (SNS) and the "parasympathetic nervous system" (PNS). Sympathetic nerves originate in the vertebral columns near the middle of the spinal cord. Their formation begins at the first thoracic segment (chest area) of the spinal cord, thus the SNS has a "thoracolumbar outflow" of nerves that extends downward to the third lumbar area (lower back area) of the spinal cord. The sympathetic nervous system is often used to describe the term "fight or flight" as a response to a perceived danger. This is the common way to explain the "sympatho-adrenal response" of sympathetic fibers and glands that secrete acetylcholine that, in turn, secrete adrenaline (epinephrine) and noradrenaline (norepinephrine) that prepare smooth muscle response for action. To a lesser extent, these automatic responses also take place prior to simple everyday movements of the body such as walking, waving your arms, eating, and so forth that may or may not require conscious response. Other functions performed by the sympathetic nervous system are the rate of the heartbeat, the level of blood pressure, and other automatic regulatory functions that are performed without intervention of conscious thought. In addition, the SNS is responsible for the following: widening bronchial passages; decreasing peristalsis movement of the large intestine, constricting blood vessels, dilation of the pupils in the eyes; erection of the dermal papillae, commonly known as "goose bumps"; and perspiration.

In 1870 Langley demonstrated that the use of an extract from a plant containing the drug pilocaine could slow the rate of the heartbeat that was exactly the reverse reaction of the drug atropine on the heart rate, and that the effects of both of these drugs were not dependent on the functioning of the vagus nervous system. Likewise, pilocaine stimulates the formation of saliva in the mouth whereas atropine inhibited the production of saliva. In the early 1900s Langley demonstrated that the drug nicotine causes contractions in muscles, while the drug curare causes the contracted muscles to relax. These experiments led Langley to the theory that drugs do not act directly on muscles but rather on an accessory substance that is actually the recipient of the drug stimuli and that, subsequently, transfers the contractual material to the receptive substance of the muscle.

LANGMUIR'S THEORIES OF CHEMICAL BONDING AND ADSORPTION OF SURFACE CHEMISTRY: Chemistry (Physical): *Irving Langmuir* (1881–1957), United States. Irving Langmuir was awarded the 1932 Nobel Prize for Chemistry.

Electrons surround the nuclei of atoms in successive layers: *The electrons surrounding a nucleus progress in number from two, located in the closest layers (orbit), followed by additional layers containing eight, eight, eighteen, eighteen, and thirty-two electrons successively.*

It was understood for some years that because the atom is neutral, it must have as many negative electrons as positive protons. It was also determined that the electrons in the outer layer (orbit or shell) are held with the weakest force to the positive nucleus. In other words, their "energy level" is less than the electrons located in the inner orbits closer to the nucleus. Therefore, these outer electrons must be responsible for different atoms combining in specific ratios to form molecules, or for similar atoms to combine to form simple diatomic molecules, such as O_2 or Cl_2 (*see* Figure S2 under Sidgwick). Two models for the structure of atoms were proposed by Niels Bohr's quantum concept of a "solar system" atom and Gilbert Lewis' idea that electrons are shared as "bonds" to form molecules. Both of these models were based on Langmuir's "layered" structure for an atom's electrons (*see also* Bohr; Lewis).

Langmuir's adsorption theory: *The adsorption of a single layer of atoms on a surface during a catalytic chemical reaction is controlled by the gas pressure if the system is maintained at a constant temperature.*

While working as a research scientist at General Electric's research laboratory in Schenectady, New York, Irving Langmuir developed light bulbs containing inert gases (such as argon) that did not oxidize the bulb's filaments. He also lengthened the life of the bulbs by using tungsten filaments, which further reduced oxidation. As a result, he theorized that electrons from the metal filament interact with monolayers (single layers) of atoms or molecules adsorbed to the surface. His theory is related to the **adsorption** of single layers of an element (usually a gas such as hydrogen) on the surface of another element (note that a*d*sorption is not the same as a*b*sorption). For example, the chemical reactions that take place inside an automobile's catalytic converter occur when the hydrogen compounds formed by the burning of the hydrocarbons in gasoline are a*d*sorbed on the platinum metallic beads inside the converter. This means the exhaust gases resulting from combustion are spread on the surface of the platinum, where they are converted to less toxic gases. These hydrocarbon atoms and molecules are not a*b*sorbed as a sponge a*b*sorbs water but rather obey the laws of surface chemistry (a*d*sorption).

LAPLACE'S THEORIES AND NEBULAR HYPOTHESIS: Physics: *Marquis Pierre Simon de Laplace* (1749–1827), France.

Laplace's theory of determinism: *What affects the past causes the future.*

In 1687 Sir Isaac Newton published his laws of motion, which were deterministic and mechanical in that they explained the movements of objects on Earth as well as celestial bodies. Aware of perturbations and irregularities in the motions of planets and other heavenly bodies, Newton also believed the universe would end if these irregularities were not somehow corrected. The Marquis de Laplace believed these irregularities did not indicate the presence of some massive destructive force because they were not cumulative. In other words, forces generated by these perturbations did not combine as one big force, ending in disaster. Rather, they were of a periodic nature and occurred at regular time intervals. He believed the future is determined by past events. This theory became known as *Laplace's demon.* In essence, it states that what has affected things in the past will also cause the future. Laplace thought that if all data were known and analyzed, this information could then be stated in a single formula and there would be no uncertainty. Thus, the future would be caused by the past. This is an old concept that could not be supported once new and more difficult equations were explored. The concept of the past causing the future can be expressed by linear equations or straight-line conceptualizing; new nonlinear equations and methods of reasoning provided more branches or alternative causes resulting in a multitude of possible effects (e.g., chaos theory).

Laplace's nebular hypothesis: *The solar system was formed by the condensing of a rotating mass of gas.*

The concept of swirling bodies in the universe originated with the ancient Greeks, but it was Laplace who tried to establish his nebular hypothesis by using Newtonian principles and mathematics. His concept stated that a ball of gas formed the sun, and from this the planets were "thrown off" their normal circular orbits, which in turn "threw off" their moons from their normal orbits. The nebular hypothesis has been updated as a rotating cloud of gas that cooled and contracted, and as it rotated centrifugal force resulted in matter forming individual rings of matter, which further contracted to form planets and moons. The great mass of leftover condensing gas formed the sun and other bodies in the solar system.

Laplace's theory of probability: *Mathematics can be used to analyze the probability (chance) that a specific set of events will occur within the context of a given set of events.*

Probability is the likelihood of a particular cause resulting in the occurrence of a particular event (effect). Today, most scientists apply probability theory to the study of many fields of science, such as thermodynamics and quantum mechanics. The probability scale ranges from 0.0 that indicates an event is highly uncertain or unlikely to occur (or will not occur) to the probability of 1.0 for high certainty or it is likely that an event will or did occur. The terms "possible" and "impossible" are not measurable and thus have no meaning when considering probability as related to an event.

See also Fermat; Gauss; Ulam

LARMOR'S THEORIES OF MATTER: Physics: *Sir Joseph Larmor* (1857–1942), Ireland.

Larmor's theory of electron precession: *An electron orbiting within the atom will wobble when subjected to a magnetic field.*

Sir Joseph Larmor's concept of matter was a synthesis referred to as the electron theory of matter. This was a rather radical description for the structure of atoms, the nature of matter, and the electrodynamics of moving bodies that relate to kinetic energy. The *Larmor precession* describes the behavior of an orbiting electron when moving through a magnetic field. The axis of the electron actually changes its angle (precession) while moving in the field and thus appears to wobble. Larmor then calculated the rate of energy that radiated from an accelerating electron, an important concept for future work in particle physics.

Larmor's concept of the aether: *Space is filled with an aether partially composed of charged particles.*

Sir Joseph Larmor was one of the last physicists who attempted to justify the existence of an **aether** (or ether) in space, believing that it was necessary as a medium to provide a means for waves (e.g., light, radio, and other electromagnetic waves) to travel from one point in space to another. (His reasoning was that water waves require the water as a medium to travel from one place to another.) He also believed aether must contain some electrically charged particles in order for matter and light to traverse space. These concepts were accepted in classical physics, but Einstein's theories of relativity made the concepts, such as the aether, invalid. Even so classical physics made some valuable contributions to the field.

LAURENT'S THEORIES FOR CHEMICAL "EQUIVALENTS" AND "TYPES": Chemistry: *Auguste Laurent* (1807–1853), France.

Laurent's chemical equivalents: *A definite distinction between atoms and molecules exists based on their equivalent weights.*

Auguste Laurent classified molecules composed of two atoms, such as oxygen, hydrogen, and chlorine, as *homogeneous compounds that become heterogeneous compounds when they are "decomposed."* Laurent's work established the relationships of the elements' atomic weights to their other properties and characteristics. This concept of atomic weight as being related to an element's chemical properties provided a key to Mendeleev's arrangement of the elements in his **Periodic Table of Chemical Elements**.

Laurent's type theory: *Organic molecules with similar structures can be assigned to a classification of "types."*

From the days of alchemy, scientists placed different chemicals and minerals into separate categories for the purpose of classification. These grouping were usually based on the "types" of color, physical consistency, or reactions with each other, but usually not on their basic elementary structures. Laurent's work with chemicals provided the distinctions needed to develop types of compounds, which were arranged according to his concepts of their structures. For example, he considered water to be one type of compound and alcohol another. Although both are composed of hydrogen and oxygen atoms, each is different in structure. His theory of types was helpful in classifying organic compounds but was not adequate for describing their different structures. Nevertheless, it was a step in the right direction toward understanding the structure and nature of organic compounds.

LAVOISIER'S THEORIES OF COMBUSTION, RESPIRATION, AND CONSERVATION OF MASS: Chemistry: *Antoine Laurent Lavoisier* (1743–1794), France.

Lavoisier's theory of combustion: *The gas emitted when cinnabar (mercuric oxide ore) is heated is the same as the gas in air that combines with substances during combustion (burning).*

Antoine Lavoisier was a meticulous scientist who at first believed in the "phlogiston" theory (*see* Stahl). However, his experiments soon indicated there was another explanation. When he burned sulfur and phosphorus in open air, they gained weight, while other substances lost weight. He concluded that something in the air, not the "phlogiston" in the substance being burned, was involved in combustion. In 1774 Joseph Priestley determined that cinnabar, when heated, emits a gas that made a candle burn more brightly and a mouse that was placed in this air more lively. Taking this further, Lavoisier believed the gas produced by cinnabar was the same as one of the gases in air that combined with substances as they burned. He later named this gas *oxygine*—Greek for "acid producer." Lavoisier then proceeded with several experiments, one of which was to repeat Priestley's experiment of burning a candle in an upturned jar placed in a pail of water. As the flame in the candle was slowly extinguished, the water level in the jar rose. He also burned a candle in the gas produced by heating cinnabar. The results were the same; thus, his conclusion was that the gas in air was the same as the gas emitted by burning the cinnabar (mercuric oxide, HgO). After the candle burned out, the gas remaining in the jar was inert and made up a large portion of the volume inside the jar. Because mice could not live in this leftover gas, Lavoisier concluded it would not support life as did his "oxygine." He called this inert gas *azote*, meaning "no life" in Greek. This gas is now called nitrogen.

Lavoisier's theory of respiration: *Animals convert pure air to fixed air.*

Antoine Lavoisier was the first to test experimentally Joseph Priestley's concept that normal air lost its phlogiston during combustion and respiration. First, he placed a bird in an enclosed bell jar. When it died, he tried to burn a candle in the air left in the jar. It would not burn, and according to the science of the day, the air was then pure, or as they said, it was "dephlogisticated" air. In other words, the bird had used up the phlogiston. Conducting other experiments with burning candles, Lavoisier hypothesized that as more air was available to the burning candle, more of it would be converted to "fixed air." In 1756 Joseph Black first prepared and named fixed air, or carbon dioxide. Carbon dioxide gas dissolves in water, as Priestley later discovered when he "invented" carbonated soda water. But the proportion of the gas consumed by the candle to the proportion of the gas left in the jar indicated there was some other gas that made up the remaining air in the jar. At the time it was not known that oxygen composes only about one-fifth of a given volume of air, while nitrogen gas makes up most of the remaining four-fifths. Nevertheless, Lavoisier was the first to measure the amount of oxygen consumed and carbon dioxide emitted through animal respiration. He was also the first to measure the heat produced by respiration and determined it could be compared to the amount of oxygen required to burn charcoal. He changed the concept of phlogiston to the concept of caloric, referred to as weightless fire that changed solid and liquid substances into gases. Science was no longer saddled with the misconception of the phlogiston theory.

Lavoisier's law of conservation of mass: *The mass of the products of a chemical reaction are equal to the mass of the individual reactants.*

When some metals are "roasted" at a high temperature in the presence of air, their surface turns into a powder called an **oxide**. In Lavoisier's time this coating of metallic oxide was referred to as *calx*. The old phlogiston theory explained the loss of weight in the air to the loss of phlogiston. Because metals gained weight during smelting, it was believed the calx combined with the charcoal and that the charcoal contained phlogiston. We now know this is not a true concept. To make careful measurements of the burned substances, Lavoiser invented a delicate balancing device that could measure a tiny fraction of a gram. Using his balance, he conceived his law of conservation of mass which is still valid today. Lavoisier is known as the father of modern chemistry due to his use of step-by-step experimental procedures, making careful measurements, and keeping accurate records.

See also Black; Priestley; Scheele; Stahl

LAWRENCE'S THEORY FOR THE ACCELERATION OF CHARGED PARTICLES: Physics: *Ernest Orlando Lawrence* (1901–1958), United States. Ernest Lawrence was awarded the 1939 Nobel Prize for Physics.

> *When charged particles are accelerated in a vertical magnetic field, they move in accelerated spiral paths.*

Since the discovery of natural radioactivity, it was known that alpha particles (helium nuclei with a positive charge) were ejected from the nuclei of radioactive substances and could induce other nuclear reactions. A method to increase the acceleration of charged particles by using electromagnetic forces was needed to penetrate and "smash" atomic nuclei to separate their component particles. To achieve the greatly increased speeds for charged particle "projectiles," John Douglas Cockcroft and Ernest Thomas Sinton Walton developed a low-energy linear (straight line) accelerator in 1929. Their "atom smasher" used a voltage multiplier to build up a high-voltage capacity capable of accelerating alpha particles beyond the speed from which they are emitted naturally from radioactive elements. However, these early linear accelerators did not provide the energies required to "smash" the nuclei of atoms to the extent that they produced smaller particles.

Ernest Lawrence proposed a unique design to solve the problem of early linear accelerators' not having adequate energies to interact with heavy nuclei to produce smaller nuclear particles. He constructed two D-shaped metal halves of a hollow circular device with a small gap between the two semicircular Ds with the vertical portion of the Ds facing each other. He named his first model the *cyclotron*, which was only four inches in diameter. By shooting charged particles into the semicircular "Dees" and then applying high-frequency electric fields to the particles, they reached tremendous speeds as they continued to circle in increasing spirals inside the Dees, getting an electromagnetic "push" each time they passed the gap (something like repeated pushes making a swing go faster and higher). As the spiraling particles approached the inside rim of the Dees, they achieved maximum acceleration. At that point they were directed toward targeted atoms, which created smaller bits of subatomic particles and energies as a result of the collisions. Lawrence's early device was the precursor of the current circular accelerators that are several miles in diameter and develop very strong electromagnetic fields aided by cryogenic superconductivity (*see* Figure V2 under Van der Meer). For the current giant atom "smasher," the particles (alpha, beta, and other subatomic particles) are accelerated by a powerful linear accelerator, which then feeds the particles into the giant cyclotron, thus combining a linear device to a circular one. These giant particle accelerators generate very high electron voltages (eV), which are a measure of the energy of the particle. Physicists continue to use these powerful devices to produce many different types of subnuclear particles, which may help explain the basic nature of matter, energy, and life. Lawrence's original cyclotron produced particles with only about 10,000 to 15,000 electronvolts (eV). Advanced particle accelerators are being developed that could reach 300 billion electronvolts (BeV) per nucleon (proton or neutron). These will be much larger and many times more powerful than the cyclotrons used in the latter part of the twentieth century. The greater the power of these new accelerators to increase the speeds at which particles slam into each other, the more information will be obtained to answer questions as to the nature of the universe.

LEAKEYS' ANTHROPOLOGICAL THEORIES: Anthropology: *Louis Seymour Bazett Leakey* (1903–1972), *Mary Douglas Nicol Leakey* (1913–1996), and *Richard Erskine Frere Leakey* (1944–), England.

> *To give meaning to where humans are today, we need to explore where we have come from; being able to look backward gives the present a root.*

Louis Leakey was the patriarch of a family of three generations who spent their lives contributing to the evolutionary study of humans. Louis Seymour Leakey married Mary Douglas Nicol Leakey in 1936. She has also made paleontological history in her own right. They had three sons. One son, Richard Erskine Frere Leakey, born in 1944, also became an anthropologist and paleontologist. Richard's wife Meave Leakey and their daughter Louise Leakey have continued the three-generational Leakey dynasty's contributions in paleontology, archaeology, and paleontology.

Louis Leakey was born in British East Africa (now Kenya) in 1903 where his parents were missionaries at the Kabete Mission near Nairobi. Louis found his first fossil at the age of twelve, which was instrumental in forming his life-long interest in archaeology. After graduating from Cambridge University in England in 1926, he returned to Africa to prove or disprove Darwin's theory that this continent was the site of the origin of human evolution. This led him to explore in more detail the large 30-mile-long chasm called the Olduvai Gorge made famous when the German entomologist Wilhelm Kattwinkel (dates unknown) discovered it in 1911. In the meantime Louis' first marriage to Frieda Leakey ended in divorce in 1933 after he fell in love with Mary Douglas Nicol, a twenty-year-old who had no formal education. They made a good team. Together they studied and determined that the stone tools that they had discovered were formed by early humans. Leakey's first major find was a well-preserved jaw of a prehuman called *Proconsul africanus*. During World War II he became a spy for the British government and later acted as an interpreter. He also became interested in writing in the fields of conservation, African natural history, and the psychological behavior of ancient humans. He became famous for his writings about Mary's (along with a collaborator of Leakey's) discovery of what they called *Zinjanthropus boisei*, a large skull with teeth that he claimed was six hundred thousand years old. Later this date was disputed when carbon-14 dating of artifacts proved it to be otherwise. The new date for this find at this particular site was 1.75 million years old.

Mary Douglas Nicol Leakey was born in London, England, in 1913 to a landscape painter who often moved to various international sites. After her father's death, her mother enrolled her in a Catholic convent school from which she was often expelled. About her experiences in the school she said that it was "wholly unconnected with realities of life." Soon after, she began her self-education by attending lectures on geology and archaeology at the University of London. She was a good artist and became an illustrator for several books on archaeology. In the early 1930s she worked at several stone-age "digs" in England, including Windmill Hill near Stonehenge and at Hembury near Devon, where she drew skillful illustrations of stone-age tools. In 1934 she was responsible for her own "dig" at Jaywick Sands in Essex at which time she published her first scientific paper. Mary met Louis Leakey at a dinner party, and less than a year later he asked her to marry him after he had left his wife. In October 1934 he left for Tanzania, and Mary followed him the following April. They were married December 24, 1936. As Louis went his own way, Mary did field work on a Neolithic site near Lake Nakuru, Kenya, where she found iron and stone tools in old home and burial sites. These discoveries led to her recognition as a professional archaeologist. Louis spent more time in London raising money for additional archeologicalal work in Africa while Mary spent the next years at the Olduvai Gorge site. Consequently, around the late 1960s they spent more and more time living separate lives, both professionally and personally. In 1978 Mary made her most famous discovery of well-formed footprints of a child and two adults. These prints proved to be 3.6 million years old and were impressions made in volcanic ash at a site in Tanzania called Laetoli. They belonged to a new species of hominids related to the 3.2 million-year-old skeleton of Lucy that was found in Ethiopia by Donald Johanson (*see* Johanson). This led to a dispute with Johanson as to the ages of these prehumans.

Richard Leakey is the second son of Louis and Mary Leakey born in 1944, who soon followed in the footsteps of his parents when he found his first fossil, parts of an extinct giant pig, at age six. (He has an older brother Jonathan and younger brother Philip. A sister Deborah died in infancy in 1943.) During his school years he was mostly interested in learning how to track animals, and at age seventeen he left school to start a successful photographic safari enterprise. He joined a fossil-hunting group in 1967 that searched the Omo Valley in Ethiopia for fossils. On an airplane trip to Nairobi he observed out the plane's window what looked like a sedimentary rock formation that might contain some fossils. Later he formed a team to excavate the area on the shores of Lake Turkana. This site proved to be very productive over the next thirty years for Richard and his team of paleontologists as they collected over two hundred ancient hominid fossils. Their most famous "find" was the cranium of the almost complete 1.6 million-year-old *Homo erectus* skull discovered in 1984 and which they named "Turkana Boy." After his first marriage failed, he married a fellow paleontologist, Meave Epps, in 1970. After serving as director of the National Museums of Kenya from 1968 to 1989, he joined the Kenya Wildlife Service as its director. In this position he spearheaded the effort to end elephant poaching that helped stabilize the elephant population in that area of Africa. Later in life he felt the lack of a formal higher education had hindered his reputation as a paleontologist and archaeologist. Richard Leakey survived a near-fatal plane crash in Kenya in 1992 but lost both legs as a consequence. Always a polarizing and controversial figure, his career as a politician and activist has been contentious.

Meave E. Leakey's early education was in boarding and convent schools. Later she received several college degrees including a PhD in zoology from the University of North Wales in 1965. She met Richard Leakey when she joined his expedition at a new site on the shores of Kenya's Lake Turkana. They have two children, one of whom, Louise, followed in her parents' and grandparents' fossil-hunting footsteps. The National Museums of Kenya where Richard was the director until 1989 also employed Maeve and Louise. Maeve Leakey made an impressive find in 1999 when she discovered a 3.5-million-year-old lower jaw and skull of what turned out to be an unknown branch of early hominids. She named this new genus *Kenyanthropus platyops,* which stands for "flat-faced man of Kenya." Since joining the National Museums of Kenya in 1989, she has focused on finding evidence of the earliest human on Earth. She is working on sites that are yielding fossils that are between eight and four million years old. One of the oldest she found represents a new species *Australopithecus anamenis*. This finding resulted in the revision of the timeline for the evolution of humans by several millions of years. In some ways Maeve Leakey's accomplishments have surpassed those of her husband and mother- and father-in law. With Louise following in the paths of her parents and grandparents, the Leakey fossil-hunting dynasty continues.

LEAVITT'S THEORY FOR THE PERIODICITY/LUMINOSITY CYCLE OF CEPHEID VARIABLE STARS: Astronomy: *Henrietta Swan Leavitt* (1868–1921), United States.

> *The periodicity of the brightness of Cepheid variable stars can be used as a standard to determine the distance to the group of stars (galaxy) in which the variable star is found.*

Henrietta Leavitt is one of science's ignored women who made important contributions to astronomy. The daughter of a Congregationalist minister, Leavitt became progressively more deaf throughout her lifetime, which did not handicap her contributions to science, although her accomplishments were not recognized until late in life. She graduated from Radcliffe College in 1892 and soon after accepted a position as a research assistant at Harvard College Observatory. Her job was that of a human "computer." In those days, educated women performed the work that today is accomplished by modern digital computers to analyze mathematical data. In her case, she was a human "number cruncher." She viewed thousands of photographic plates of the stars made by the astronomers at the Harvard Observatory and recorded and analyzed the data—mainly to measure and catalog the brightness of stars recorded on plates. She viewed thousands of images of stars found in the polar region of the Magellan Cloud. In 1908 she published her conclusion that some of the variable stars showed patterns of brightness. She observed that the brightest variable stars known as **Cepheids** had longer periods of brightness than did the less bright stars. She also proved that this relationship between luminosity and periodicity was predictable. This relationship between a star's brightness and its period of variable brightness was soon recognized, and the value of this discovery was soon used to measure the distance of stars from Earth. In 1913 the astronomer Ejnar Hertzprung used this relationship as a yardstick to measure the distance from Earth of several Cepheids located in the Milky Way. Later, this relationship was again used to measure the distances of the variable stars in the Andromeda galaxy. The analysis of this data proved that stars located at great distances indicated they were located in other galaxies and were not in the Milky Way.

> The relationship between a Cepheid variable star's luminosity and its period of variability has been used as a standard measure of a star's distance for about the past hundred years. Sometime later, it was learned that most Cepheids belong to the classification of *population I stars,* and therefore are called Type I Cepheids. There are slightly different types of variable stars known as Type II Cepheids. Cepheids are large bright yellow stars that have an oscillation of their luminosity caused by regular and precise expansion and contraction. Cepheids have periods ranging from one day up to about fifty days and their luminosity doubles from their dimmest to their brightest. This cycle of expansion and contraction is caused by stars' using up their supply of hydrogen fuel, causing instability, and resulting in pulsations between their dimmest to brightest periods. Also, ionization of helium gas in the Cepheid's atmosphere varies with this cycle of the star's atmosphere resulting from the state of its helium gas. The star's ionized helium that is closest to the sun has a greater density and thus is more opaque to the star's light than is the gas further from the sun where it is deionized and thus less dense. This factor sets up a cycle between the two states of helium gas, which can be correlated to the Cepheid's mean density as well as its luminosity and, more important, as a measure of the star's distance from Earth. The precision with which a star's distance can be determined by this relationship between a star's luminosity and periodicity led to its use as a standard "candle" to measure, with some degree of accuracy, the distance of the brighter stars.

Leavitt measured and established the relationship between luminosity and periodicity for many hundreds of Cepheid variables. She also determined that that there is a relationship between the lengths of the periods of brightness. A three-day period for one type of Cepheid exhibits a luminosity eight hundred times that of our sun. Another type, that is, a thirty-day period Cepheid, has a luminosity about ten thousand times that of our sun.

In 1921 the American astronomer Harlow Shapley, as director of the Harvard College Observatory, appointed her as head of stellar photometry at the Observatory. However, she died later that year. Henrietta Swan Leavitt never received much recognition for her theory and discoveries. An asteroid was named the 5383 Leavitt Asteroid and a crater on the moon is named after her. She was considered for nomination for a Nobel Prize by Swedish mathematician Gösta Mittag-Leffler (1846–1927), but because she had already died the nomination was rejected by the Committee.

See also Hertzsprung; Shapley

LE BEL'S THEORY OF ISOMERS: Chemistry: *Joseph Achille Le Bel* (1847–1930), France.

The asymmetric quadrivalent carbon atom can form molecules composed of the same atoms but with different structures.

Earlier chemists worked on various theories to explain the structure of atoms and how they bonded (joined) with other atoms to form molecules of different compounds. This dilemma was solved when it was determined that carbon had a tetrahedron structure. Joseph Le Bel devised his concept of the asymmetric carbon atom at about the same time as did another chemist, Jacobus Van't Hoff. Both of their concepts were based on the tetrahedron structure of the carbon atom with its four valence electrons arranged something like a three-legged tripod, with the fourth bond pointing up (*see* Figure V3 under Van't Hoff). Le Bel's concept for the structure of the carbon atom was published in 1874, just two months before Van't Hoff published his almost exactly similar discovery. The tetrahedron structure of the carbon atom indicated how other carbon atoms or atoms of other elements, in pairs or individually, combined with carbon to form inorganic and organic molecular compounds. This would produce **isomers** of compound molecules that had the same chemical formula but different physical characteristics, such as boiling points, color, and reactivity. This concept ultimately resulted in the development of organic (carbon) chemistry and explained the myriad existing organic molecules. Although there are some inorganic compounds that contain carbon, for example, carbon dioxide (CO_2) and cyanide (CN), all organic compounds contain carbon (e.g., all living matter and products of living matter, including all foods whether sold as organic or not). This is why organic chemistry is referred to as "carbon chemistry."

See also Kekule; Van't Hoff

LE CHATELIER'S PRINCIPLE: Chemistry: *Henri-Louis Le Chatelier* (1850–1936), France.

Any change made in a system in equilibrium results in a shift of the equilibrium in the direction that minimizes the change.

In essence, Henri-Louis Le Chatelier's principle describes what happens within a system that is in equilibrium (symmetry, parity, stability, or balance) when the factors of temperature, pressure, or volume change. If there is an increase in the pressure, the system decreases its volume to bring itself back into equilibrium. This principle includes the law of mass action and the theory of chemical thermodynamics. Le Chatelier's concept provides scientists with a mathematical interpretation of the system's dynamics and a practical physical means to control what occurs within a system where the changes in pressure and temperature cause the system to readjust its equilibrium. Le Chatelier's principle is invaluable for understanding how to control the mass production of industrial chemicals (e.g., ammonia and hydrocarbon products, such as gasoline).

See also Boyle; Haber

Henri-Louis Le Chatelier made another contribution to science in the field of thermometry that was based on German physicist Thomas Seebeck's idea for a thermocouple. In 1826 Seebeck (1770–1831) demonstrated that when two different metals that are placed together and heated, a current will flow between them, and the current will be proportional to the differences in the temperature of the metals forming the junction where the metals meet. Le Chatelier conceived the idea of using an alloy metal for one side of the junction. He successfully placed platinum metal on one side of the junction and an alloy of platinum/rhodium on the other side where the temperature was to be measured. Keeping the platinum metal of the junction at a constant temperature allowed the temperature on the alloy metal side of the junction to be calculated by measuring the amount of current flowing through the junction between the two metals.

Working in his grandfather's mines with the structure of alloy metals and their temperature differences when exposed to heat, Le Chatelier arrived at his principle of how the temperature, pressure, and volume were related to the concept of equilibrium in 1887. His principle was challenged and later replaced by two laws proposed by Jacobus Van't Hoff. The first law states *an increase in pressure will favor the system that has the smaller volume*. The second law states *a rise in temperature favors the system with absorption of heat*. This law explains the equilibrium existing for reversible chemical reactions that are expressed by using a double arrow ($\Longleftrightarrow$) as in the equation expressing the exothermic reaction that take place during the formation of ammonia: $N_2 + 3H_2 \Longleftrightarrow 2NH_3$.

LEDERBERG'S HYPOTHESIS FOR GENETIC ENGINEERING:

Biology (Genetics): *Joshua Lederberg* (1925–2008), United States. Joshua Lederberg shared the 1958 Nobel Prize for Physiology or Medicine with Edward Lawrie Tatum and George Wells Beadle.

> *If viruses can inject themselves into the genes of bacteria cells to cause infections, then it should be possible to inject genes into animal cells.*

Joshua Lederberg's first experiments demonstrated that bacteria contain genes in their nuclei and at times reproduce by sexual mating, as well as by conjugation. Previously it was believed bacteria reproduced only by "fission," where the mother cells split into two new daughter cells without any interchange of genetic material. This is known as asexual reproduction. Lederberg demonstrated that when crossing different strains of bacteria, a mutant strain would develop randomly, which caused a mixing of genetic material between the two strains. Because the crossed bacteria could develop their own colony of bacteria, sexual mating must be occurring. Occasionally he found that some enzymes were destroyed by what are called *bacteriophages*, which are viruses that enter and infect bacteria, thus causing genetic changes (*see* Figure D7 under Delbruck). Lederberg and Max Delbruck proved that new strains of viruses result when two different strains are combined in a form of sexual reproduction just as occurs for bacteria. Their work led to the new science of genetic engineering, where genes can be recombined by inserting them into bacteria and other cells.

See also Delbruck

LEDERMAN'S TWO-NEUTRINO HYPOTHESIS: Physics: *Leon Max Lederman* (1922–), United States. Leon Lederman shared the 1988 Nobel Prize for Physics with Melvin Schwartz and Jack Steinberger.

The two different types of neutrinos are generated by different physical decay processes.

When beta particles (electrons) were ejected during radioactivity, the end particles exhibited less energy than expected. To explain this seeming negation of the law of conservation of energy, the neutrino was postulated to account for the missing energy. (The Italian physicist Enrico Fermi named the neutrino, which means "little neutral one," in the 1930s.) Even though neutrinos may be considered "nonparticles," they do exist, as do "antineutrons." Both are important to maintain the symmetry and mathematics related to particle physics. Leon Lederman recognized that there are two different decay processes controlled by the weak interaction between subatomic particles that produce neutrinos. One decay process occurs when pions decay into muons (μ) plus neutrinos ($V\mu$). The result is the formation of one type of neutrino that Lederman hypothesized is different from the other type. The second decay process is a form of beta decay, where a neutron (n°) is converted into a proton (p^+) by ejecting an electron (e^-) and a neutrino (V) (*see* Figure F2 under Fermi). In other words, Lederman attempted to find out if the muon-related neutrino was the same particle as the electron-related neutrino. His experiment with his two colleagues, Melvin Schwartz (1932–2006) and John Steinberger, resulted in the identification of the existence of the muon neutrino ($V\mu$), and the ability to distinguish it as a different subatomic particle from the electron plus neutrino combination emitted when a neutral neutron is converted to a positive proton.

See also Fermi; Pauli; Steinberger

LEE'S THEORIES OF WEAK NUCLEAR INTERACTION: Physics: *Tsung-Dao Lee* (1926–), China and United States. Tsung-Dao Lee and Chen Ning Yang shared the 1957 Nobel Prize in Physics.

Parity is not conserved in interactions between elementary particles.

The conservation of parity for the classical laws of physics is the concept that these laws are symmetrically the same for all special axes or coordinates. This means that the results of experiments viewed as a mirror image themselves will produce the same results. Parity was assumed to be a natural universal law of conservation for the classical concepts of gravitation and electromagnetism, for instance, when negatively charged particles are balanced by positively charged particles (e^- and p^+). Another example is when the strong force that holds together the nuclei of atoms is in parity with the weak force exhibited by radiation. Or the conservation of parity can be related to the symmetry or the right-handed image to the mirror left-handed image. The laws of nature were long thought to be the same under mirror reflections of right/left and thus were the same under the same conditions in the universe. In 1956 Tsung-Dao Lee and his collaborator Chen Ning Yang discovered that the weak force involving the weak nuclear interaction between elementary particles (gravity and electromagnetism) maximally violated parity. These two physicists and other scientists provided experimental evidence that the right–left symmetry involved in the weak force was not consistent and in fact maximally violates parity. Their work led to the formation of the "Standard Model" for particle physics in 1968 that describes the theory for the two electromagnetic weak interactions developed by Sheldon Glashow, Abdus Salam, and Steven Weinberg.

See also Fermi; Glashow; Salam; Weinberg; Yang

LEEUWENHOEK'S THEORY OF MICROSCOPIC LIFE: Biology: *Anton van Leeuwenhoek* (1632–1723), Holland.

Multitudes of living "animalcules" exist in water and other fluids.

Anton van Leeuwenhoek is sometimes, and incorrectly, credited with inventing the microscope. Leeuwenhoek is best known for developing improved microscopes in the seventeenth and early eighteenth centuries, but he did not invent the instrument. His design consisted of one small lens fixed between two metal plates. The object to be observed was placed on a "pin" that could be focused by moving the object up and down by turning a screw device. During his lifetime, he constructed and sold over five hundred models of his microscopes. When he died, he left 247 completed instruments plus over 170 mounted lenses. Most have disappeared, and only nine of his original microscopes have survived.

He based his theory of "little animalcules" on a lifetime of observing the microscopic world around him. He was the first to observe and describe protozoa in water, bacteria in his own feces, red blood cells, nematodes in soil, rotifers, and ciliates such as *vorticella*, bacteria with different shapes, *spirogyra* (alga), and human sperm. Some of his descriptions were very accurate and led to further investigations. He examined the plaque and sputum from his mouth and the mouths of others and then described the strong actions of these multitudes of "animalcules" found in spittle as "fish swimming in water." This was the first viewing and written description of bacteria. As early as 1684, Leeuwenhoek calculated that red blood cells were twenty-five thousand times smaller than specks of sand. He also made extensive observations of microscopic fossils, crystals, minerals, as well as tissues from a variety of animals and plants. His microscopes were used to view the microscopic world rather than for scientific purposes, whereas his drawings and descriptions proved valuable for future biologists.

See also Galileo; Janssen

LEIBNIZ'S THEORY FOR "THE CALCULUS": Mathematics: *Gottfried Wilhelm Leibniz* (1646–1716), Germany.

Finite areas and volumes for curves can be calculated by use of differential and integral mathematical calculations.

The dilemma of how to determine the area on or within a curved surface had been explored by dozens of mathematicians, philosophers, and scientists since ancient Greece. Leibniz realized a workable notation method (the use of symbols to represent quantities) was required to solve problems related to the areas and volumes of curves. His solution to the notation problem was: $\int ydy = y^2/2$, which is still used today. Leibniz published the results of his calculus in "Mathematical Calculations for the Investigations and Resolutions of Multiple Variables" in 1684, which turned out to be a significant event in mathematics. A major dispute as to the discoverer of calculus resulted when Sir Isaac Newton, who had developed his calculus much earlier in 1665, delayed publication of his calculus until 1687. Therefore, Leibniz is credited with the discovery and development of calculus. It seems that Leibniz learned about Newton's letter to a mutual friend that described his mathematics related to calculus. Thus, he was aware of Newton's procedures for solving the problem. The basis and origin of calculus became a dispute among mathematicians as well as the two principles in question. Their differences were greater than just who invented calculus. Leibniz also disagreed with Newton's theory of gravity. Leibniz, using Aristotle's metaphysical concept of motion, claimed that a body is never moved in nature unless and until another body moves it which results in the first body's motion and continues until another body acts on it. Later it became clear that Leibniz used different notations of symbols to represent quantities in his calculations that were based on his unique invention of differential and integral calculus.

See also Newton

LEISHMAN'S HYPOTHESIS FOR PARASITIC DISEASES: Biology (Bacteriology): *Sir William Boog Leishman* (1865–1926), England.

Leishman's hypothesis: *Oval bodies imbedded in spleen tissue are responsible for protozoan infections related to parasitic diseases.*

William Boog Leishman was born and educated in Glasgow, Scotland, followed by a tour in the British Army Medical Services in India until 1897 when Leishman returned to England. He became an assistant professor of pathology in the Army Medical School in 1900. While at this post, he developed a new method of staining blood that could be used to identify malaria and other types of parasites. This new stain was a combination of Methylene Blue and eosin and became known as *Leishman's stain.* A few drops of the stain are placed on a slide with a specimen of the blood from a patient where it sets for 20 seconds. Then more drops of a buffer solution at pH6.8 is mixed with the stain. After a short period, it is then washed off before viewing the specimen with a microscope. In 1901 while examining tissue from the spleen of a patient who had died of *Kala-Azar,* he used his stain to identify tiny oval bodies imbedded in the spleen tissue. He hypothesized that these bodies were responsible for the protozoan infection that caused the disease called *Kala-Azar.* Two years later another physician with the Indian Medical Service, Charles Donovan (1863–1951), independently made the same discovery of the protozoan that causes *Kala-Azar.* It was originally named *Leishmania donovani*, but later this category of protozoan became known as *Leishmaniasis.* It was determined that *Leishmaniasis* is transmitted by the bite of the female sand fly that injects its saliva into the victim as it sucks out some blood from its bite while depositing some protozoa. This disease has many names and is found in over eighty-eight countries. It was known as far back as two thousand years ago and is identified by many names, including Kala-azar, black fever, Aleppo or Oriental boils, white leprosy, Andean sickness, sand fly disease, valley sickness, espundia, or Dum Dum fever. It is estimated that over twelve million people are now infected worldwide and several hundred millions more are at risk.

Leishman was also instrumental in the development of a number of vaccines, particularly typhoid which afflicted large numbers of native populations, as well as members of the military serving in indigenous regions. Due to the success of a typhoid vaccine, by 1909 Leishman reported that only five out of nearly eleven thousand vaccinated soldiers died in India, compared to the deaths of forty-six out of almost nine thousand soldiers who were not vaccinated died. Fewer than two thousand British soldiers died of *Leishmaniasis* by the end of World War I.

During World War II in 1943 about one thousand U.S soldiers stationed in the Middle East came down with the cutaneous version of *Leishmaniasis*. There are three distinct versions of the sand fly disease: the *cutaneous* (skin), the *visceral* (internal organs), and *mucocutaneous* (mucus membranes) that exhibit different symptoms. The most common is the cutaneous *Leishmaniasis*, which is caused when the parasite in the saliva of the female sand fly burrows in the wound. The protozoa in the saliva multiply rapidly until there is a visible ulceration, which festers and takes months to heal. The small circular lesions are painless but often leave scars. Although it is recommended that treatment be sought, the wound will heal itself in time. It is not certain, but it is possible that the infection will be with the patient for life.

Even though a significant number of U.S. troops were deployed in Iraq during Desert Storm in 1990, there were only thirty-two confirmed cases of *Leishmaniasis*. One reason is that the major sand fly season is from the end of March to September. Because most of the service personnel involved in Desert Storm left Iraq before the main season of sand fly infestation, they were not infected. The same did not occur during the more recent Operation Iraqi Freedom campaign where hundreds of troop serving in Afghanistan and Iraq were infected. The main treatment center for U.S. military personnel is the Walter Reed Army Medical Center in Washington, D.C. A second center was opened at the Brooke Army Medical Center in San Antonio, Texas. Treatment consists of ten to twenty days of intravenous infusion of the drug called Pentostam. Freezing the protozoan at the infected site with liquid nitrogen can treat mild cases. Even unsightly lesions will take more than a year to heal. At last report about two hundred service men and women decided against treatment and let the lesions called "the Baghdad boils" heal on their own. Although military experts expect an increase in cases of *Leishmaniasis*, with better housing facilities and rotation of personnel experts believe the number of cases in the Middle East will decline. Currently, there is no vaccine available.

LEMAÎTRE'S THEORY FOR THE ORIGIN OF THE UNIVERSE: Astronomy: *Abbé Georges Edouard Lemaître* (1894–1966), Belgium.

> *Contrary to Einstein's belief in a static universe, Lemaître believed that the theory of relativity requires an expanding, not static, universe.*

Georges Lemaître was one of the first astronomers to relate relativity to cosmology. He based his nonstatic universe on the supposition that if matter is expanding everywhere within the universe, then there must have been a moment in the past when this expansion began. Although he disputed Einstein's belief in a static universe, Lemaître based his own thesis on Einstein's theory of special relativity of space-time. Lemaître assumed that if we could revert far enough in time, we would see the entire universe as a very compact, compressed point of matter and energy. He also considered radioactivity as the force that caused the original explosion, an idea no longer considered a valid theory for the big bang. Unfortunately, Lemaître did not completely calculate the mathematics for his theory of an expanding universe. From the later 1920s to the early 1940s, his expansion theory was unpopular with other astronomers, who still considered a static universe the preferred model. The most important aspect of Lemaître's theory was not just the expansion concept (which was well known), but the idea that something started the whole process—that is, there was a physical origin to the universe. In the late 1940s, Lemaître's theory of an expanding universe was revived and revised by George Gamow, who named it the "big bang." Today, it is considered one of the most likely explanations for the origin of the universe.

See also Einstein; Gamow

LENARD'S THEORY FOR ELECTRON EMISSION: Physics: *Philipp Eduard Anton Lenard* (1862–1947), Germany.

During the photoelectric effect, the speed of electrons emitted is a function of the wavelength of the light (electromagnetic energy) involved.

Philipp Lenard based his research on the photoelectric effect first detected by Heinrich Rudolph Hertz. Lenard observed that when ultraviolet light "struck" the surfaces of certain kinds of metals, electrons were "kicked" out and could be detected. He designed experiments to determine the cause and found that the speed at which electrons are ejected from certain types of metal during exposure to the light was a function of the wavelength of light used. Further, he found the shorter the wavelength of light used, the greater the speed of the emitted electrons. At the same time, the intensity of the light had no effect on the electrons' speed, but the brighter the light, the greater quantity (number) of electrons emitted. Some years later, Einstein explained the photoelectric phenomenon by relating it to Planck's quantum theory.

See also Einstein; Hertz; Planck

LENZ'S LAW OF ELECTROMAGNETICS: Physics: *Heinrich Friedrich Emil Lenz* (1804–1865), Russia.

Lenz's law can be written in several forms. They all are special examples of the law of conservation and are extensions of Michael Faraday's Law of induction of a magnetic field by the flow of an electrical current in a conductor. There are various ways of stating Lenz's law. Several examples follow:

1. *The EMF induced in an electric circuit always acts in such a direction, that the current it drives around the circuit opposes the change in magnetic flux, which produces the EMF.* (Note EMF stands for "electromotive force" which is the difference in potential that exists between two dissimilar electrodes immersed in an electrolyte.)
2. *The induced current produced in the conductor always flows in such a direction that the magnetic field it produces will oppose the change that produces it.* (In essence, this version of the law states that in a given circuit with an induced EMF caused by a change in a *magnetic flux*, the induced EMF causes a current to flow in the direction that opposes the change in flux. Note: *magnetic flux* is related to the magnetic induction that is perpendicular to the surface. It is better known as the density of a magnetic field.)
3. *The current induced by a change flows so as to oppose the effect producing the change.* This law is related to the more general law of conservation of energy and is a

special case because if the induced current were to flow in the opposite direction in the conductor, it would be an example producing electrical energy without any work being done (perpetual motion), which is impossible according to the law of conservation of energy.

Heinrich Lenz was born in Tartu (present-day Estonia). After finishing secondary school he attended the University of Tartu. Upon graduation, he was appointed as the geophysicist on two expeditions around the world from 1823 to 1826, where he made important measurements of the climate and physical conditions at various geographic locations. Following these tours he became dean of mathematics and physics at the University of St. Petersburg in Russia where he remained until 1863. He began his studies of electromagnetism as early as 1831. In addition to discovering Lenz's law he also independently discovered a version of Joule's law in 1842, which in Russia, is referred to as the Joule–Lenz law.

See also Faraday; Joule; Ohm

LEVENE'S TETRA-NUCLEOTIDE HYPOTHESIS: Biology: *Phoebus Aaron Theodor Levene* (1869–1940), Russia and United States.

The DNA molecule is composed of a string of four nucleotide units consisting of equal amounts of adenine, guanine, cytosine, and thymine.

In 1909 Levene found that pentose sugar *ribose* is found in the nucleic acid of yeast. However, it was not until 1929 that Levene identified the carbohydrate in the nucleic acid of the thymus. Because its molecule lacked one oxygen atom of ribose, it was called *deoxyribose*. These discoveries prompted Levene to hypothesize that a simple tetranucleotide (a combination of four nucleotides) was responsible for the structures later named *ribonucleic acid* (RNA) and *deoxyribonucleic acid* (DNA). This led to his "tetranucleotide hypothesis" that stated that DNA was composed of equal amounts of *adenine, guanine, cytosine,* and *thymine.* It was Levene who demonstrated that the components of DNA were linked in the order of phosphate-sugar-based units he called nucleotides that formed the backbone of molecules of living organisms. Regrettably, his concept (and thus hypothesis) for the structure of DNA was wrong because he believed that only four nucleotides exist in each molecule. To his credit, Levene recognized that his four-nucleotide concept was not able to account for a system to store the genetic code for living organisms because it was much too simple. Nonetheless, his hypothesis provided the basis for additional study, and the later discoveries that finally led many scientists to work on the puzzle of the structure of the famous double helix of the DNA molecule, which provides the copying mechanism for the genetic material. Crick, Watson, and Maurice Wilkins received the 1962 Nobel Prize for Physiology or Medicine. (Rosalind Franklin, who was Wilkins' assistant and coauthor provided the crystal photos of the DNA molecular structure that provided the clues to the unique helix structure of the molecule.) One of the amazing revelations about the structure of DNA is that one DNA molecule of one human cell, if laid end to end would be about 1 millimeter in length, which is many, many times longer than the cell itself.

See also Crick; R. Franklin; J. Watson

LEVI-MONTALCINI CELL GROWTH THEORY: Biology: *Rita Levi-Montalcini* (1909–), Italy and United States. Rita Levi-Montalcini shared the 1986 Nobel Prize for Physiology or Medicine with Stanley Cohen.

> *A naturally occurring protein molecule in the body of living organisms, known as the nerve growth factor (NGF), stimulates the growth and differentiation of the sympathetic and sensory nerves.*

The nerve growth factor (NGF) is a protein secreted by the target cells of the neurons and is critical for the well-being and maintenance of the sympathetic and sensory nervous systems. This procedure is responsible for the movement of NGF in long-distance signaling of neurons. NGF binds two receptors on the surface of cells that respond to the two types of growth factors, that is, Track A (TrkA) and low infinity nerve growth factor receptors (LNGFR). These factors activate the signaling of nerve impulses between the stimulated cells and the receptor cells. Levi-Montalcini's research has led to advances in the regeneration of various types of nerves. It has been discovered that sensory nerves have greater potential for rehabilitation than do motor neurons. Although some nerve cells can and do regenerate if damaged, it is hoped that research using fetal stem cells will lead to improved treatments to restore or replace damaged nerve cells.

Rita Levi-Montalcini was born into a Sephardic Jewish family of four children raised by a mathematician father and talented painter mother. Her father did not want her to go to college, but she insisted and entered the Turin Medical School. She graduated with an MD degree in 1936. Her career was cut short due to Mussolini's law that barred Jews from academic careers. During World War II she set up a home laboratory in her bedroom where she studied the growth of nerve fibers in chicken embryos. Her family fled to Florence where she set up another home laboratory. In 1946 she received and accepted an invitation to Washington University in St. Louis, Missouri, to spend a semester as a research assistant. She stayed for thirty years. While at Washington University, she did her best and most important work and became a full professor in 1958. In 1961 she became director of the Research Center of Neurobiology in Rome, Italy, where she split her time between Italy and United States. Levi-Montalcini was only the tenth woman ever elected to the U.S. National Academy of Sciences. In addition to receiving the 1986 Nobel Prize (shared with Stanley Cohen), she also received the Albert Lasker Award for Basic Medical Medical Research. In 1987 she received the National Medal of Science, considered by some the highest honor in science in the United States. Still active in Italian politics, she was appointed a Senator-for-Life in 2001 in the Italian senate.

LEWIS' THEORY OF COVALENT BONDS: Chemistry: *Gilbert Newton Lewis* (1875–1946), United States.

> *When atoms combine to form molecules, they share a pair of electrons, thus forming covalent bonds.*

Ionic bonds, also called polar bonds, were first introduced in the late 1800s and were thought to be one-to-one sharing of electrons from one atom to another. **Ionic bonding**

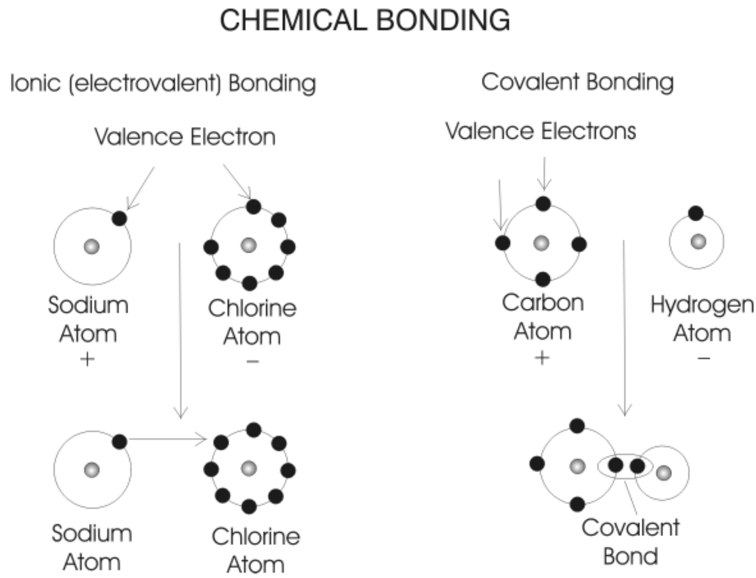

Figure L1. Examples of two types of bonding—*ionic* where one or more electrons are exchanged between atoms and *covalent* where one or more electrons are shared.

occurs when atoms with a dearth of negative charges (electrons) in their outer orbits (valence) naturally attract electrons from other atoms to complete their outer orbit. These atoms now form a molecule of a new and different more stable compound and are now neutral as they have lost their individual electrical valence charge (*see* Figure L1).

However, this concept was not valid for the formation of all molecular compounds. Lewis first conceived the structure of atoms as cubes with the possibility of one electron located at each of the eight vertices (corners) of the cube. More complex atoms were structured with smaller cubes located inside larger cubes. Lewis soon rejected this cube structure, but he still believed that at least eight electrons were required for each neutral atom. This knowledge led to the Lewis–Langmuir octet theory (*see* Langmuir), which provided information about the atomic structure of rare gases in which all eight vertices of their cube are occupied. Therefore, because the atoms of these gases do not gain, lose, or share electrons, they are inert because electrons occupy all the eight vertices of their cube image. This also explained why atoms that did not have a complete octet of outer electrons were available to combine with other atoms, by either ionic bonding or sharing electrons as covalent bonds. All atoms have a natural tendency to attain the same octet formation and thus become more stable (inert). For example, sodium has only one vertex (in its imaginary cube structure) occupied by an electron, while chlorine has seven vertices (in its cube) occupied. Sodium and chlorine act to establish the stable octet structure; thus sodium gives up its one electron, and chlorine accepts it, satisfying both. (For instance, $^{+}Na + {}^{-}Cl = NaCl$, where the salt NaCl is neutral, is an example of ionic bonding, while $^{--}O + {}^{--}O = O_2$ depicts a pair of atoms sharing electrons, that is, covalent bonding to form a diatomic molecule of oxygen gas.) The most common type of covalent bonding is single bonding where just two electrons are shared—one from each partner. There may be double bonds as well, involving four shared electrons, or even triple bonds, with six shared electrons. Lewis and Langmuir's octet theory resulted in a better understanding of the laws of thermodynamics and the periodic arrangement of elements.

See also Langmuir; Sidgwick; Thomson

LIEBIG'S THEORY OF ISOMERS AND ORGANIC COMPOUND RADICALS: Chemistry: *Justus von Liebig* (1803–1973), Germany.

Inorganic or organic compounds (molecules) with the same formula can have different structures and thus exhibit different characteristics.

Justus Liebig was working with Joseph Louis Gay-Lussac when he discovered *silver fulminate*. At the same time, his friends Friedrich Wohler and Jöns Jacob Berzelius had prepared *silver cyanate*. To the surprise of all, both of these compounds had the same formula, but they behaved very differently. Berzelius named this phenomenon ***isomerism.*** Today, this concept is used to develop different chemicals that have the same basic formulas but exhibit many different and useful properties. Isomerism is one of the reasons so many different types of organic (carbon-based) synthetic drugs, manmade fibers (nylon), polymers, plastics, dyes, cosmetics, bleaching agents, and numerous other organic chemical products can be manufactured. Exploring this phenomenon further, Leibig and Wohler used different forms of the benzoyl radical (a form of benzene C_6H_6) combined with other elements to formulate their theory of compound radicals. This is an example of a family of similar chemicals that can have additional atoms added to the main radical. Chemists can use the basic benzoyl radical to form different compounds by adding, for example, chlorine (Cl), bromine (Br), hydrogen (H), nitrogen (N), or other atoms to the basic structure.

See also Kekule; Lewis

LINDEMANN'S THEORY OF PI: Mathematics: *Carl Louis Ferdinand von Lindemann* (1875–1939), Germany.

It is impossible to "square the circle" to arrive at a rational number for pi (π) by using a straight edge and compass and thus accurately determine the area of a given circle.

Carl Lindemann was aware of Archimedes' method of using geometry (multiple polygons) to determine the value of pi by "squaring the circle" to determine the ratio of the circumference of a circle to its diameter (or radius). Historically, mathematicians wished to use this ratio (pi) to determine the area of a circle ($A = \pi r^2$). Archimedes arrived at a ratio of 3.142, which is very close to the current accepted value of 3.14159. Lindemann used algebraic methods to prove that an accurate ratio for pi could not be determined by geometric methods using a straight edge and compass because pi is a transcendental number. All transcendental numbers are irrational and a real number is said to be transcendental if it is not an algebraic number. This means that pi is not a root for any polynomial equation with rational coefficients, such as $2/3x^3 - 5/7x^2 - 21x + 17 = 0$.

See also Archimedes

LINNAEUS' THEORIES FOR THE CLASSIFICATION OF PLANTS AND ANIMALS: Biology: *Carolus Linnaeus* (1707–1778), Sweden.

> *Plants and animals of different species can be classified according to similarities within a species as well as differences between species.*

All classification systems use some form of similarities and differences between and among what is being classified. Aristotle's taxonomy or classification of living things was based on the assumption that nature proceeds from tiny lifeless forms to larger animal life with no distinct line of demarcation between classes. He designed what is called the "ladder of life" that assigned each species to a lower or higher step on his ladder (*see* Figure L2).

Until Linnaeus' time, plants and animals were classified from the top down, beginning with large classes and working down to smaller groups. Carolus Linnaeus devised the system of taxonomy based on the concept of species that is still in use today. A major factor in determining what animal or plant belongs in a particular species is whether reproduction is limited within that species. We know today that the vast majority of DNA is the same for all mammals. However, just a small difference of DNA between species prevents cross-fertilization. For instance, chimpanzees and humans share over 98% of

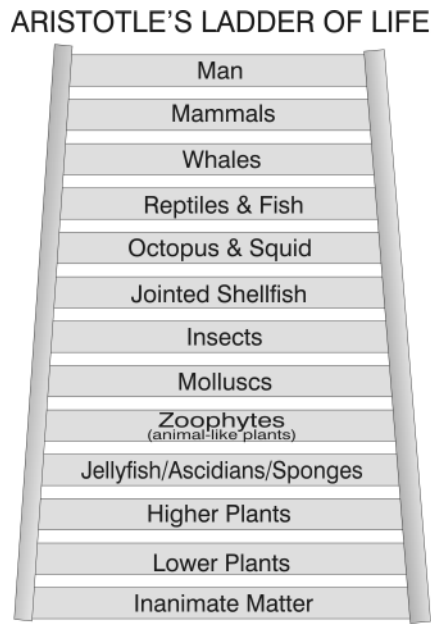

Figure L2. Linnaeus partly based his classification of plants and animals on Aristotle's hierarchy of life that started with man on top and extended to lower plants and finally inanimate matter.

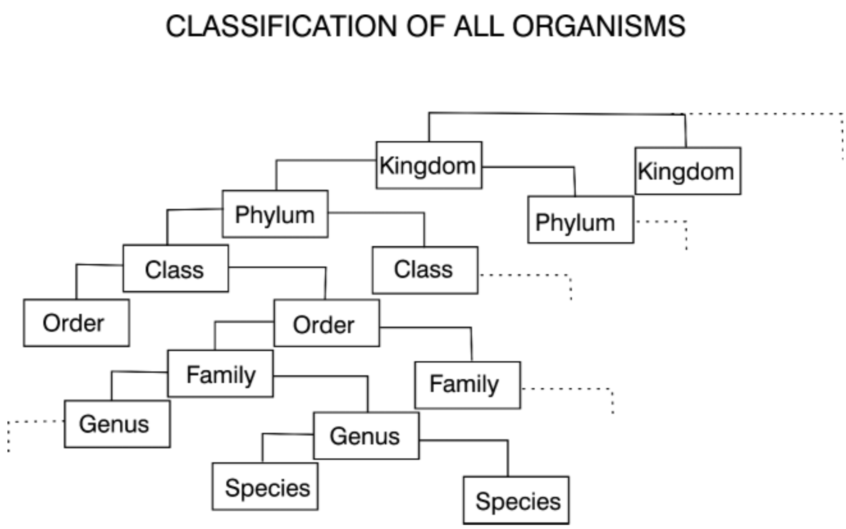

Figure L3. Linnaeus' classification of plants and animals was an advancement from Aristotle's and is similar to what is the current taxonomy.

the same type of DNA. Linnaeus further classified according to similarities within a species as well as differences between species. His concept required a new terminology, for which he used Latin names. Starting with humans, he used *Homo* as the genera for "man" and *sapiens* for the species of "wise man." From here Linnaeus combined similar *genera* into *family*, from family up to larger groups called *orders*, then divided further into *phyla*, and phyla into the two *kingdoms* of plants and animals (*see* Figure L3).

The term "taxon" is meant to encompass all the special traits shared at any of the seven major categories of his taxonomy system. Since then, subdivisions have been added, and with the knowledge of evolution and cellular and molecular distinctions, even finer similarities and differences are used. More recently, biologists have divided the two kingdoms of plants and animals into five major groups. This new classification system consists of three major plant kingdoms and two major animal kingdoms. These distinctions are based on differences in molecular DNA.

See also Cuvier; Darwin; Lamarck

LISTER'S HYPOTHESIS OF ANTISEPSIS: Biology: *Baron Joseph Lister* (1827–1912), England.

> *Carbolic acid, used during surgical procedures, can prevent and control subsequent infections.*

Joseph Lister based his hypothesis on and credited the work of Francesco Redi and Louis Pasteur. Redi determined that rotting meat developed maggots only when exposed to flies, and Pasteur proved that microorganisms caused such putrefaction. Using this knowledge of airborne microorganisms, Lister sprayed the air of operating rooms with carbolic acid (a derivative of benzene called phenol). To his dismay, deaths from infections following surgery were still over 50%. He then soaked a cloth in carbolic acid and used it to bind an open wound. The wound healed without infection. Following this lead, Lister then soaked all his surgical instruments in carbolic acid, had surgeons rinse their hands in dilute acid, and maintained a clean operating room. These procedures reduced surgical mortality in his operating rooms in 1877 from 50% to about 5%. At first, Lister's hypothesis for controlling infection was not well received; subsequently by the late 1800s antiseptic procedures were standard in all hospitals and doctors' offices. Lister made another contribution when he replaced silk thread, which was used for sutures and could not be easily sterilized, with catgut disinfected by carbolic acid. Today steam is used in autoclaves to sterilize medical instruments, as well as a variety of disinfectants and anti-infectives to prevent infections.

See also Pasteur; Redi

LOCKYER'S SOLAR ATMOSPHERE THEORIES: Astronomy: *Sir Joseph Norman Lockyer* (1836–1920), Britain.

> *A unique spectral line from the sun's light is produced by a new and unknown element.*

Sir Joseph Lockyer spent much of his life attempting to determine the composition of the sun's atmosphere and its effects on Earth. He and Pierre-Jules-Cesar Janssen devised a method of observing the sun during daylight hours. Up to this time, the only way to view the sun was during a solar eclipse or through a smoky-colored glass produced by holding it over a burning candle that deposits a thin film of carbon on the glass. In 1868 Janssen, using a solar spectroscope, was the first to view a peculiar spectral line in sunlight that did not match other known spectral lines. Although he was the first to see this spectrum, it was later identified and named by Lockyer, who hypothesized that because it existed only in the sun, it should be called helium, from the Greek word *helios* meaning "sun." Helium was considered a hypothetical element until detected on Earth twenty-five years later by Sir William Ramsay. Lockyer made other contributions. Using the Doppler effect (*see* Doppler), he determined the "wind speed" of solar flares. In addition, he determined the temperature of the surface of the sun and that sunspots have a lower temperature than the sun's surface. Lockyer also was convinced the solar atmosphere affected Earth's weather because its orbit is just at the edge of the sun's outer corona. Additionally, he believed the size and number of sunspots affect the amount of rainfall on Earth. At the time, he was unable to examine these phenomena, which today are partially accepted, but not as Lockyer hypothesized.

See also Doppler; Janssen; Ramsay

LORENTZ'S PHYSICAL THEORIES OF MATTER: Physics: *Hendrik Antoon Lorentz* (1853–1928), Netherlands. Hendrik Lorentz shared the 1902 Nobel Prize for Physics with Pieter Zeeman.

Lorentz's electron theory: *Atoms and molecules are very small, hard bodies that carry either a negative or positive charge.*

James Clerk Maxwell determined that light waves were the result of the vibrations of charged particles (atoms); as these particles oscillated, electromagnetic waves were produced. Hendrik Lorentz's electron theory expanded this theory and was based on the assumption that 1) there is a wave-carrying medium in space known as **aether** and 2) matter (solid, liquids, and gases) was a separate entity from the wave/aether, therefore 3) only electrons could interact between them. He found that atoms with a positive charge "oscillate" in one direction within a magnetic field, and those with a negative charge "oscillate" in the opposite direction. His mathematical theory was developed before there was any proof that electrons existed, but it indicated that light waves were the result of oscillating electrically charged atoms.

Lorentz force: *There is a force applied to moving electrically charged particles when they are in the presence of an electromagnetic field.*

Hendrik Lorentz identified charged particles produced in a cathode ray tube as negative electrons. His theory also explained the Zeeman effect (*see also* Zeeman), which asserted that the spectral lines for sodium atoms split into several closely spaced lines when exposed to an electromagnetic field. This phenomenon was later explained by quantum theory.

Lorentz's theory for the contraction of moving bodies: *Light from moving bodies traveling through the aether caused these bodies to appear to contract in size in the direction of their motion.*

At about the same time Lorentz proposed his theory for the contraction of moving bodies, another physicist, George Francis Fitzgerald, independently arrived at the same concept. Therefore, the mathematics for this phenomenon is known as the *Lorentz–Fitzgerald contraction*. In essence, the theory states that bodies moving through an electromagnetic field contract somewhat in the directions of their motion in proportion to their velocity. This explains why light appears to move at the same speed in all directions at the same time from its source. Einstein used this concept in developing his theory of special relativity (*see also* Einstein; Fitzgerald; Zeeman).

Lorentz invariant: *Natural laws must be invariant to a change in the coordinates (space and time) of any system.*

The Lorentz invariant is sometimes referred to as the Lorentz transformations theory. The theory is based on the mathematics Hendrik Lorentz developed to explain how moving bodies seem to contract. The consequence of these theories is that both space (three dimensions) and time must be equally considered when developing any type of equation that explains the relative motion of matter. The theories of contraction and transformations describe the coordinates that need to be considered for the contraction in the length and the increase in mass of moving bodies at relativistic speeds. They provided the foundation for Einstein's theory of special relativity. Einstein relied on the mathematics of Hendrik Lorentz and also recognized the contributions made by other scientists that aided him in developing his theories of relativity.

See also Einstein; Fitzgerald; Maxwell; Michelson; Zeeman

LORENZ'S THEORY FOR COMPLEX/CHAOTIC SYSTEMS: Mathematics: *Edward Norton Lorenz* (1917–2008), United States.

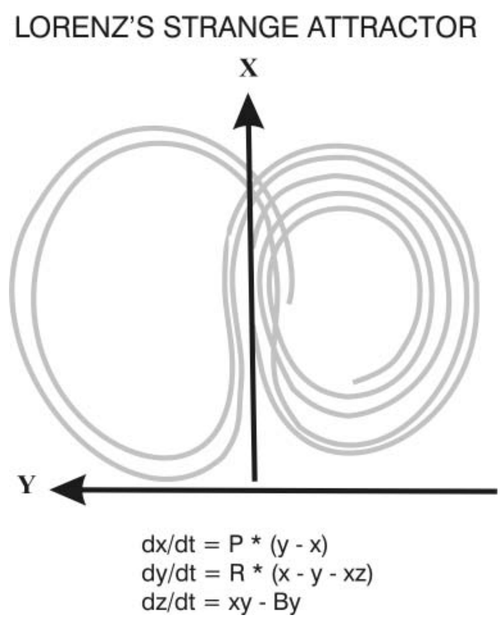

Figure L4. Lorenz's strange attractor depicted as a curve on a plane surface, which is actually a curve in three-dimensional space. The line forming the curve is a single unbroken line that never follows the same path and, in three dimensions, never intersects itself.

The sensitivity of a dynamic system depends on small initial conditions.

Edward Lorenz, a meteorologist, applied mathematics to weather forecasting and climate changes. Using a computer, he analyzed the initial conditions of a weather system with temperature as the only single variable. His original data were carried out to six decimal places but rounded off to three decimal places, a practice used by most scientists and which Lorenz assumed was such a small difference that it would not affect the outcome. This assumption proved to be false because he obtained a different result each time he ran the computer data. At this point, he realized that small initial differences do have a cumulative effect over long periods of time and thus affect events differently. This phenomenon that describes the sensitivity of a system as dependent on small differences in initial conditions became known as the "butterfly effect." The butterfly effect hinges on a number of weather factors, including the temperature and humidity of the air and how the air is flowing. It aptly describes the chaotic systems in which small perturbations result in very different outcomes. The name *butterfly effect* came from a fable about a butterfly whose flapping of its wings created an air flow in China that added to the cumulative air flows around the world, thus causing hurricanes in Florida and snowstorms in Wisconsin. The principles of complex systems, chaos theory, and nonlinear mathematics are used to interpret dynamic systems as diverse as economic cycles, the stock market, population changes, the dynamics of three-dimensional flow of fluid in pipelines, the dynamics of prehistory archaeology, and weather predictions. Edward Lorenz originated the *Lorenz attractor*, a mathematical expression using differential equations to describe how a system settles down, based on the three variables of space orientation (x, y, and z). Diagrams of this concept are looping curves on a two-dimensional surface, but the curves are in three dimensions where the single line never crosses itself at any given moment of time (*see* Figure L4). A point on the line represents a variable of the system expressed as a point in three-dimensional space.

See also Penrose; Wolfram

LOVELL'S THEORY OF RADIO ASTRONOMY: Astronomy: *Sir Alfred Charles Bernard Lovell* (1913–), England.

> *Radio signals collected from outer space can be used to verify the existence of many phenomena, such as quasars with angular diameters of less than one second of arc. They also have the ability to track meteors and comets.*

Bernard Lovell received his PhD from the University of Bristol in 1936 and served on the cosmic ray research team of the University of Manchester until he entered military service during World War II. He used his talents working on wartime aircraft radar for which he received an award. After the war, he continued his work with radar to detect cosmic rays using surplus army radar equipment. Before the war in the United States, Nikola Tesla had recorded extraterrestrial cosmic rays as radio-type signals on his experimental radio equipment. Most of the scientific community did not believe this electronics genius because they rejected the notion that cosmic rays existed. In the early 1930s the Bell Laboratory engineer Karl Guthe Jansky detected radio waves from the center of the Milky Way galaxy. The American radio astronomer pioneer Grote Reber (1911–2002) confirmed Jansky's discovery a few years later. It was not until after World War II that the field of radio astronomy became a major research effort for England and the United States.

Lovell was convinced that extraterrestrial radio waves were a possible tool for advancing theories in the field of astronomy. Lovell installed surplus wartime radar equipment at Jodrell Bank in the Cheshire region in England. Thus began his life-long research investigating cosmic rays, tracking meteor velocities, and comets. He soon realized that he needed a much larger and steerable radio telescope dish that could receive radio waves of at least 30 centimeters. Because this was before the days of "big" research budgets, Lovell had difficulty raising funds for the project, but he persevered. The 250-foot diameter dish could be steered to pick up signals from locations in space from horizon to horizon. In 1957 the Lovell Telescope at Jodrell Bank was used to track *Sputnik*. It has proven to be an excellent investment ever since as it is used for teaching and research by students and engineers in cooperation with other types of telescopes. Although the Lovell telescope has been upgraded and is still in use, a number

In the year 2004 there was a scientific breakthrough that confirmed Percival Lowell's conjecture that at one time there was water on the planet Mars. However, there was no evidence to support this belief that canals were dug to transport the water from the polar regions to the dryer equatorial areas of the planet. The evidence that water once flowed over the surface of Mars was confirmed by two six-wheeled robots—the Spirit and Opportunity—that landed on the red planet's surface in January 2004. Their lifetimes for sending signals back to Earth was estimated to be just three months, but they roamed over many kilometers, even in Mar's subfreezing winters, sending information to Earth for far longer. According to a major U.S. science journal, *Science,* the success of these two robots and the value of the geological data gathered and transmitted to Earth was a major triumph. The robots were even able to determine that the water on Mars was salty, and acidic, and possibly capable of supporting life. NASA hopes to send a robot to the Martian polar ice sheet in 2008 and a mobile laboratory in 2009 to answer the following questions: Where and when water may have flowed in the past on Mars? Where it might be found today? And, what forms and amounts might be available for use? Although more robots will be sent to Mars, the moon, and other planets, the ultimate goal is to, in the not too distant future, send humans to Mars to conduct extensive geological research.

of more technologically sophisticated and larger radio telescopes have since been constructed.

See also Jansky; Tesla

LOWELL'S THEORY OF LIFE ON MARS: Astronomy: *Percival Lowell* (1855–1916), United States.

> *Canals and oases seen on Mars indicate that it was once inhabited.*

Percival Lowell became interested in the 1877 report by Giovanni Schiaparelli in which he stated that he observed *canali* (Italian for "channels" or canals) on the surface of Mars. Lowell constructed a 24-inch reflector telescope atop a 7,200-foot mountain in Arizona to make use of the area's clear sky. He reported he also saw Schiaparelli's Martian canals and claimed they were built by intelligent beings. He theorized these canals were dug to transport water from melting ice at its poles to the dry central regions of the planet. It is now known that these lines and patches were aberrations in Lowell's lens/mirror system, the "shimmering" of Earth's atmosphere, or the results of a vivid imagination.

See also Schiaparelli

LYELL'S THEORY OF UNIFORMITARIANISM: Geology: *Sir George Lyell* (1797–1875), Britain.

> *Currently observed geological changes and processes are adequate to explain geological history.*

This basic concept was first expressed by the Scottish geologist and naturalist James Hutton (1726–1797) and John Playfair (1748–1819), the Scottish mathematician and philosopher, some years before Lyell clarified it. However, both neglected to explain fully or examine their concept in detail. Sir Charles Lyell explicitly stated that the same scientific laws and geologic processes that applied in the past, and the present, and that will also apply in the future are, therefore, responsible for the physical and chemical processes that result in geologic changes. This led to his famous saying, "The present is the key to the past." He explicitly rejected the theory of German geologist

Abraham Werner, who believed that a huge deluge of water (the "flood") was responsible for Earth's current topography. Lyell believed the action of the wind, rain, the sea, earthquakes, and volcanoes, rather than some great catastrophe, explained geological history. He rejected the concept of catastrophism, which was first believed to conform to biblical history. Lyell based much of his "uniformitarianism" concept on his study and classification of the strata of ancient marine beds. He observed that the layers of sediment closest to the surface contained shells as well as the remains of animal species still living in modern times. Conversely, the deeper, older strata contained more fossils of extinct species. He divided the rocks containing fossils into three groups, or epochs and named them after ancient geological periods—Eocene, Miocene, and Pliocene—terminology still in use today. Charles Darwin, who developed the theory of organic evolution, relied on parts of Lamarck's and Lyell's earlier works.

See also Darwin; Eldredge–Gould

LYSENKO'S THEORY OF THE INHERITANCE OF ACQUIRED CHARACTERISTICS: Biology: *Trofim Denisovich Lysenko* (1898–1976), Russia.

Trofim Lysenko followed in the footsteps of I.V. Michurin (1855–1935), a Russian who advocated the acceptance of Lamarckism. Michurianism and later Lysenkoism were the biological and genetic party line (ideology) of the Soviet Union under Stalin. Lysenko, a minor agriculturalist, promoted a new theory based on an old farmers' concept, called "vernalization," as a means to improve the germination of grain. He claimed that by treating grain with cold water, the flowering of the grain would improve, and it would sprout sooner in the spring. Thus, it would take less time to raise a crop and would increase the production of grain to feed the masses. It did not work. Neither this concept nor any of his other ideas used standard controlled experiments, peer review, or other accepted processes and procedures of scientific research. His mistake, as well as those of some others in Russia, was a rejection of the science related to Mendelian genetics. His insisted that this "cold treatment" would not need to be repeated each year because, once used, it became an "acquired" characteristic that would be passed on from one generation of grain to the seeds of the next. Lysenko's ideas seemed to fit the Marxist philosophy, and he soon discredited the president of the Lenin All-Union Academy of Agricultural Sciences, Nikolai Vavilov (1887–1943), who was exiled to Siberia. Lysenko then became head of this all-powerful institution and had complete support from Joseph Stalin and the Communist party. Some, but not all, biologists in Russia believed that the theory of acquired characteristics could be applied in many instances. Lysenko believed in his new but unproven "science" that proclaimed that any desirable acquired characteristics could be inherited under the right conditions. For example, it was supposedly said that if a woman wanted a red-haired child, all she need do is dye her hair red and that characteristic would be inherited by her offspring. Russian biologists who did not support Lysenkoism but rather supported the science of modern genetics, as well as Darwin's theory of natural selection, were designated as reactionary and decadent enemies of the Soviet people. They were, over time, either excommunicated, sent to death camps, or disposed of.

See also Darwin; Lamarck; Mendel

M

MACH'S NUMBER: Physics: *Ernst Mach* (1838–1916), Austria.

> *There is a ratio that expresses the velocity of an object in a fluid to the velocity of sound in that fluid.*

Ernst Mach believed if information about nature cannot be sensed, it was useless. In addition, he thought discoveries could be made by intuition and accident (serendipity) as well as by using mathematics and scientific methods. These ideas and his concept of motion, which states that the inertia of a body arises from interactions with all of the mass within the universe, influenced the field of quantum mechanics and Einstein's formulation of his theory of relativity. His experimental work with vision and hearing led him to use high-speed photography to detect the shock wave produced in air by a high-speed bullet. This so-called barrier is also created when an airplane approaches the identical speed of sound traveling in cold air, which is about 750 (more or less) miles per hour. This "sound barrier" was first believed to be similar to a wall that must be overcome. However, there is not now, nor has there ever been, a wall to overcome. For example, it is well known that artillery shells, bullets, and thunder all travel faster than the speed of sound and produce shock waves. Air molecules are compressed and produce a shock wave. "Sonic booms" are heard when two shock waves are so close together that they are heard as a single "boom" by a bystander on the ground. The wave front for an airplane is a *V*-shaped area of compressed air analogous to the *V*-shaped bow wave produced by a speeding boat in water. The exact speed of the object traveling through a fluid (e.g., air) required to break this "barrier" will depend on the temperature of the air as well as the air's density and moisture content. The denser the medium through which sound travels, the faster it travels; at room temperature, sound travels 1,126 feet per second in air, 4,820 feet per second in water, and 16,800 feet per second in iron. The greater the density of the medium, the faster the sound proceeds

The concept of inertia (the resistance of a body to any change in momentum) is an old and often-confusing concept. Aristotle believed that once a body was in motion, some type of force was required to continue its movement—therefore there could be no action at a distance that could affect the body. Many years later Sir Isaac Newton stated his classic ''three laws of motion.'' The first law deals with inertia that states that an object with mass will remain at rest while objects in motion with a constant velocity will remain in motion at that velocity until an external force acts on the object. His concept of inertia of a body was intrinsic to a body having mass and not dependent on the existence of any other matter. Thus, once a body with mass at rest is acted on by a force and then put into motion, it would continue moving at that speed in the same direction until some other force acted on it to change its speed and direction. Newton formulated his three laws of motion against the concept of absolute space and time. Mach disagreed with this concept of absolute space and time and believed only *relative* motion, not *absolute* motion, exists in the universe. He concluded from this that it is immaterial to think that Earth revolves on its axis or that the stars in the sky do the revolving and that Earth is motionless. This became known as ''Mach's principle'' by cosmologists. Mach believed that our world was nothing but sensations, thus resulting in ''economy of thought,'' which was the simplest way to explain science phenomena. This led to the concept of ''logical positivism'' which had an influence on Einstein in the development of his theory of relativity.

through that medium. Whenever the speed of an object exceeds the speed of the sound in a particular medium through which the object is traveling, a shock wave is produced. At 0°C the speed of sound traveling through dry air is 331.4 meters per second at sea level. The Mach number varies for airplanes flying at different altitudes. At higher altitudes, the air is colder, thinner, and dryer than at sea level; thus the sound barrier is reached at different speeds at different altitudes.

The Mach number that Ernst Mach devised is the ratio of the velocity of an object, such as an airplane, to the speed of sound in air though which it travels. Mach numbers below 1 are referred to as subsonic flows of fluid; numbers greater than 1 are supersonic flows of fluid. An airplane flying at a speed lower than a Mach number of 1 will be traveling in subsonic flight. Once the airplane exceeds Mach 1, it has reached supersonic velocity, and the so-called sound barrier will be broken. As an example, if an airplane travels 1,500 miles per hour and the speed of sound in air through which the airplane is flying is 750 miles per hour, the ratio is 1,500/750 = Mach 2. The airplane overtakes the wave fronts in the front as well as in the rear of the airplane, producing overlapping wave fronts.

See also Aristotle; Einstein; Newton

MAIMAN'S THEORY FOR CONVERTING THE MASER TO THE LASER: Physics: *Theodore Harold Maiman* (1927–2007), United States.

The variable wavelengths produced by the maser can be altered to produce shorter visible coherent wavelengths.

The word "maser" is an acronym derived from the term "microwave amplification by stimulation emission of radiation" and was developed about the same time by three physicists, Charles Townes at Columbia University, and Drs. Nikolai Basov (1922–2001) and Aleksandr Prokhorov (1916–2002) of the Lebedev Institute in Moscow, Russia. The maser is a device that produces coherent electromagnetic radiation as the result of stimulated emission within a limited portion of the electromagnetic spectrum. Originally, the microwaves produced by the maser were very weak, but this was soon overcome which made it more useful for a number of applications, such as atomic clocks and radio telescopes. Therefore, some physicists have replaced the term "microwave" with "molecular" to represent their use when working with molecules that are the basis for kinetic energy.

This background provided Harold Maiman with the idea that the range of wavelengths produced by the maser could be extended to provide much shorter and visible wavelengths. The shorter white light wavelengths can travel much longer distances than those produced by the maser. While at the Hughes Research Laboratories in Malibu, California, Maiman designed an instrument that used a ruby-red cylinder-type crystal with a mirror-like finish at both ends of the cylinder. These mirrors enabled the light that entered the cylinder to "bounce" back and forth in the cylinder. The cylinder then became a resonant cavity. This provided a means for the flashes of incoherent white light of the maser to change into a pulsating beam of coherent monochromic (one color) light that could travel great distances without spreading into a wider beam. In 1961 Iranian-born physicist Ali Javan (1926–) and colleagues at the Bell Laboratories in Murray Hill, New Jersey, produced the first continuous coherent beam of light. These improvements led to the naming of this type of optical source as a LASER, which is the acronym for "light amplification by stimulated emission of radiation." Of some interest is that more recently the word "laser" (no longer capitalized) has become a standard word in the English language and thus included in most dictionaries. The verb of the word is now "lase" as in "he has been lased."

In the 1960s and 1970s scientists and engineers sought out problems for which they believed these new lasers would help to find solutions. There are many forms of lasers developed for use in industry, science laboratories, the medical field, the military, and other areas in society. Some examples: supermarket barcode scanners, laserdisc players, laser printers, surgical instruments, and in various forms of communications. There are two different types of basic lasers. One uses a high-peak output that produces high energy, short pulses, such as the Yag laser, which is a crystal composed of yttrium aluminum garnet (Y_3 Al_5 O_{12}) used for eye surgery, and the continuous wave type that produces a constant output, used mainly for communication and the cutting of hard materials. Another advantage of lasers is that it is one of the few instruments that provides more output power than the input power required to operate it. Charles Townes, Basov, and Prokhorov shared the 1964 Nobel Prize in Physics for their work on the maser. Maiman was nominated twice for a Nobel Prize but never won. He did receive the 1983/84 Physics Prize and became a member of the National Inventors Hall of Fame and the National Academies of Science and Engineering.

MALPIGHI'S THEORY FOR THE DETAILED STRUCTURE OF ANIMALS AND PLANTS: Biology (Anatomy): *Marcello Malpighi* (1628–1694), Italy.

Living materials are glandular in organization, and the largest internal organs consist of tiny glands whose function is both the separation and mixing of juices.

Malpighi was one of the first physicians to use the microscope for research and to study the internal structure of plants and animals. As a physician using his microscope, Born in Italy in 1628, Marcello Malpighi entered the University of Bologna in 1646. Despite the deaths of both his parents when he was twenty-one years of age, he managed to complete his education. His career in anatomy and medicine was continued as a professor of theoretical medicine at the University of Pisa in 1656. Later in 1659, he returned to the University of Bologna where his colleagues were critical of his microscopic research primarily because of a lack of understanding. Leaving this hostile situation, he accepted a professorship in medicine at the University of Messina in Sicily in 1662 where he and his research were welcomed. While there, he did some of his best microscopic research and was able to identify and describe taste buds in the mouth and how they were the termination of nerves that sent signals to the brain. He also described the optic nerves, some structures of the brain, and in 1666 was the first to not only see blood cells, but also determine that the red color was intrinsic to these cells. Malpighi had a long career. However, despite his many accomplishments and honors, including an honorary membership in the Royal Society in London, his last years were fraught with challenges. He was in ill health, and his many enemies, who opposed his somewhat radical ideas, burned down his house destroying his microscopes, papers, and manuscripts in 1684. In recognition of his status as a great physician/researcher, Pope Innocent XII appointed him as the papal physician in 1691. He was also named count and elected to the Italian College of Doctors of Medicine. He died in 1694 after suffering a stroke.

he made important observations in his study of the tissues and organs of plants and animals, including the human body. He is considered a pioneer in using this instrument for physiological and anatomical studies. His microscopic studies of living organs, such as the brain, spleen, liver, and urinary system, as well as larger organs, were historic. These studies led him to conclude that minute glands exist at the tissue level as well as the organ level. He theorized that these glands were designed for the separation as well as mixing of vital juices. He used his microscope for some of the first examination and study of interspecies similarity and differences of tissues and organs. He contributed several insights to the field of comparative anatomy, particularly for the skin, kidneys, and liver of various species. For instance, he discovered that silkworms and other insects do not have lungs to breathe. Rather, there are small holes in their skin called tracheae. He also discovered that food, produced by sunlight action on the green chlorophyll in leaves of plants and required for plant growth, comes downward from the leaves of trees. Most important, he was the first to observe capillaries and discern their relationship to the movement of blood between arteries and veins. For many years physicians, including William Harvey, did not understand how blood flowing through arteries entered the veins for the return trip to the heart. Malpighi's observation provided the basis for a more accurate understanding of human physiology.

Marcello Malpighi is best known as an Italian physician and biologist who pioneered the science of microscopic anatomy of living things. His research with the microscope was enormously useful in future studies in other fields, such as physiology, embryology, and general medicine.

MALTHUSIAN POPULATION CATASTROPHE THEORY: Biology (Economics): *Thomas Robert Malthus* (1766–1834), England.

> *The power of population is indefinitely greater than the power in Earth to produce subsistence for man. Populations, when unchecked, increase in a geometrical ratio.*

Malthus was an economist interested in the biology related to the growth of population outstripping the potential supply of food. The theory has received many names, such as "Malthusian dilemma," "Malthusian limit," "Malthusian disaster," and "Malthusian check on population." The theory is based on the mathematical concepts of geometric and linear progression of biological growth. The population (of any animal species) increases geometrically (i.e., 2, 4, 8, 16, 32, etc.) if no restrictions are placed on the reproduction process, whereas the increases in natural resources supporting the animal species is a linear arithmetical progression (i.e., 1, 2, 3, 4, 5, etc.). During the early period of the industrial age that began in the early nineteenth century Malthus was concerned with the decreasing death rate and increasing birth rate in Europe as the population moved from an agrarian to an industrial society. He stated two postulates. First, that an adequate supply of food must be available to sustain human existence, and second, that the natural passions between the sexes will lead to offsprings (geometric progression). After all, reproduction is the main purpose of all life; otherwise most species, including humans, will become extinct. In essence, the Malthusian population theory states that any population growing faster than the resources (food) necessary to provide for the increasing population will experience catastrophe. This is why Malthus considered the geometric (or exponential) progression of growth in the human population an impending catastrophe. One upside of biological population theory states that if the reproductive potential of virtually any organism or species greatly exceeds Earth's capacity (land, water, or food) to support all the potential offspring, many will die and, consequently, species diversity will be preserved. Thus, in the long run, the evolution of new species may be introduced. Many biologists (and economists) believe that Malthus' theory was too pessimistic, at least for humans, because it did not take into account technological advances in agricultural and food technologies such as the "green" revolution of the 1960s and, more recently, the genetic engineering of plants and animals that have led to increases in Earth's agriculture and husbandry capacity to support growing populations. Some Central and Eastern European countries, Central and Eastern as well as Southern Africa (due to HIV), England, and the United States have a negative growth in their *native* populations. However, through the emigration of people from countries that are overpopulated, these regions, with the exception of Southern Africa, now have not only a positive growth in population, but also the consequential social and economic problems resulting from seemingly unchallenged immigration. Even so, unchecked breeding by humans will in time outstrip our technological ability to support the numbers predicted to be about nine billion people within the next hundred years. Even today, there are regions of the world where the increase in population restricts the quality of life of the inhabitants of those regions. Although there are individuals and organizations that recognize the problems related to excessive population growth, unfortunately there are many more humans who ignore warnings of future consequences. Because Malthus' was an economist, his theory is considered by some to be more mathematical than biological and, therefore, is not completely accepted by all biologists.

MALUS' LAW FOR THE POLARIZATION OF LIGHT: Physics: *Étienne Louis Malus* (1775–1812), France.

When a perfect polarizer is placed in a polarized light beam, the intensity of the light that passes through the polarizer is expressed by the following equation:

$$I = I_0 \cos^2 \theta i :$$

where I is the intensity of the beam of polarized light; I_0 is the original intensity of the light beam; θ_i is the angle between the light's starting plane of polarization.

Malus graduated from a French military school and attended the École Polytechnique graduating in 1796 as a military engineer. He served as an "examiner" in physics where he was able to pursue various areas through his research projects, mainly in optics. In 1808 he made a discovery, partly by accident and partly by using his inquiring mind. By viewing the image of a house through a crystal of Iceland spar (transparent calcite used in optical instruments), he noticed that by rotating the crystal the reflected rays of the sun were extinguished, but only when the crystal was held in certain positions. Because he was a firm believer in the Newtonian corpuscular concept of light that claimed that particles of light had poles, Malus believed that the planes in the crystal's structure oriented the poles of the light particles (corpuscles), thus causing the obstruction of some of the light. He named this phenomenon "polarization." This was the first time the word was used to describe this odd behavior of light passing through a crystal.

Despite conducting research with various types of glass, Malus was unable to produce any polarization of light because of the poor quality of glass at that time. However, by using high-quality natural crystals he developed his law that gives the initial and resulting intensity of light when a polarizing crystal is placed into the path of the incident beam of light. Thus, he was able to arrive at his law related to the intensity of polarized light. Since Malus' initial endeavors, research has been conducted on many types of materials to determine the effects of polarizers.

Some examples are:

1. *Absorptive polarizers*, including the "wire-grid polarizer," that can polarize electromagnetic waves resulting from electric fields.
2. *Beam-splitting* polarizers that split a single incident beam of light into two beams of different polarizations.
3. *Polarization by reflection* occurs when light reflects at an angle from an interface between two transparent materials—depending on the orientation of the plane from which the light is reflected.
4. *Birefringent polarizers* are dependent on the birefringent properties of quartz or calcite crystals where the beam of light is split by refraction into two rays.
5. *Thin film polarizers* are special types of glass on which a substrate of special optic coatings are applied to the film, causing them to act as beam-splitting polarizers. They can be either a thin plate of glass, or a wedge of glass with the film attached in a particular orientation.

The equation related to Malus' law indicates that real polarizers are not perfect transmitters of light components. For instance, if two polarizers are placed one on top of the other, the orientation angle between their polarizing axes is determined by the θ_i in Malus' law. In theory, if the two polarizers are crossed, no light should be transmitted. However, in practice because no polarizer is perfect, the light is not completely blocked.

MANSFIELD'S THEORY OF MAGNETIC RESONANCE: Physics: *Sir Peter Mansfield* (1933–), England. Peter Mansfield shared the 2003 Nobel Prize in Physiology or Medicine with the American chemist Paul C. Lauterbur (1929–2007).

The nuclei of atoms have a magnetic moment that can be detected and used to form an image of living tissue.

Peter Mansfield based his work on that of Felix Bloch (1905–1983) and Edward Purcell who discovered that the nuclei of some atoms have a **magnetic moment**. The protons and neutrons of nuclei have spins that are not paired. This creates an overall spin on the particles, generating a magnetic dipole along the spin axis, which is a fundamental constant of physics referred to as the *nuclear magnetic moment* (μ). This can be compared to a wobbling spinning top whose axis circumscribes a precessional path, similar to the precession of Earth's axis. This wobble is created by an unbalanced spin caused by an external torque on the nucleus' axis, which results in a resonance. Absorption of electromagnetic radiation by most atomic nuclei (particularly organic compounds) in response to strong magnetic fields causes the nuclei to radiate detectable signals. The process become known as nuclear magnetic resonance (NMR) because it involved the nuclei of many types of atoms of the substance exposed to the electromagnetic radiation. This process was first used as a spectroscopic method for analyzing the atomic and nuclear structure and properties of matter. Later, the radiation produced by the resonating nuclei was detected and recorded by computers to form a two dimensional spectroscopic image of living tissue. The British electrical engineer and 1979 Nobel Laureate Godfrey Hounsfield (1919–2004) used NMR to develop a computer-aided tomography (CAT) scan that could form an image of human tissue and was less intrusive than X-rays. Mansfield improved the process by altering the manner in which magnets affected the spin of the nuclei so that a three-dimensional image could be produced. This became known as magnetic resonance imaging (MRI), which was designed to produce three-dimensional images of cross-sections of any part of the human body. However, even today confusion still exists between NMR, MRI, and nuclear energy. They are *not* the same. NMR is used as a spectroscope to view characteristics of molecules, and MRI is used to produce three-dimensional pictures of human tissues. Neither produces harmful nuclear radiation. Rather, they use powerful magnetic influences to "excite" the atomic nuclei of various types elements and to make three-dimensional images of tissues in human bodies by causing the nuclei of atoms to resonate (oscillate) differently and thus emit distinct frequencies (signals). Computerized instruments record these signals and analyze the results, thus scientists can study details of molecules and physicians are able to distinguish between healthy and diseased tissue. The word "nuclear" refers to the oscillation of the nuclei of atoms of various elements that make up living cells. The *N* of NMR has been eliminated from the term because of the public's ignorance and fear of nuclear radiation. It does not mean "radioactive," as with nuclear radiation produced by either nuclear fission or fusion. Thus, NMR has been replaced by the current term MRI of the body for diagnostic and therapeutic procedures.

See also Rabi; Ramsey

MARCONI'S THEORY OF RADIO TELEGRAPHY: Physics: *Guglielmo Marchese Marconi* (1874–1937), Italy. Marconi shared the 1909 Nobel Prize for Physics with the German inventor and physicist Karl Ferdinand Braun (1850–1918).

Using Hertzian radio waves, it is possible to create a practical system of "wireless telegraphy."

Marconi failed the entrance exams for the Italian Naval Academy and the University of Bologna. Nevertheless, he had a keen interest in science, especially electricity, and was permitted to attend lectures and laboratories at the university. He constructed his own laboratory in the attic of his home in Pontecchio, Italy, where he built his own equipment to explore what at that time were known as Hertzian waves or electromagnetic radio waves. He followed the footsteps of several other famous scientists of that period: Heinrich Rudolf Hertz of Germany, Edouard Eugene Desire Branly (1844–1940) of France, Oliver Joseph Lodge (1851–1940) of England, and Aleksandr Popov (1859–1906) of Russia. Heinrich Hertz constructed a "radiator" that consisted of two rods with a spark gap between them. Each had a capacitor at their ends to store the electricity until it reached the level where it was strong enough to create the spark between the gap, thus discharging the electricity stored in the capacitor. Hertz also designed a receiver for the electromagnetic waves produced by the spark that consisted of a loop of wire with a gap. This loop received the spark (electromagnetic wave) produced by current stored in the capacitor of the sender. The radiator sender and receiver were not connected.

This makes Hertz (or possibly Popov) the inventor of a device to send wireless radio signals—not Marconi as assumed by many people. The French consider Branly, a professor of physics, to be the inventor of the wireless telegraph by sending a spark to a receiver that responded by forming a coherent path of loose zinc and silver filings that detected the reception of the sending transmitter. Lodge, the head of physics at the University College of Liverpool, improved Branly's device by shaking the metallic crystals between sparks so the next sparks could be detected. This became the method for sending and receiving early wireless telegraph signals. Although Lodge received a patent for his device, he used it to communicate with the dead, and that was the last that was heard from him, or the dead.

It was Marconi who had the greatest insight into the potential for his device for wireless communications. At a young age Marconi made a number of unique improvements to the systems of others and patented a successful radio telegraph system at the age of twenty-two. His first units could only telegraph a dot-and-dash message a few feet, then thousands of feet, and soon a few miles. In 1901 he successfully transmitted and received wireless messages across the Atlantic Ocean. Although he did not invent wireless transmission of telegraph and radio, he made the advancements that significantly improved the process of radio telegraphy. He soon formed the Marconi Wireless Telegraph Company in England that was taken over by the British General Post Office in 1910.

MARGULIS' ENDOSYMBIOTIC CELL THEORY: Biology: *Lynn Margulis* (1938–), United States.

Primitive single-celled prokaryotes, (cells with no nuclei) engulfed other cells, and, if both survived, they evolved by symbiotic pairing in a cooperative *relationship over millions of years into eukaryotes (bacteria-type cells) that contain nuclei and other mitochondria (internal cellular structures) that drive evolution.*

Lynn Margulis was born in Chicago in 1938 and attended the University of Chicago where she received her undergraduate degree. She was married for a time to astro-biologist Carl Sagan before divorcing in the 1960s. She also attended the University of Wisconsin and later received her PhD degree from the University of California at Berkeley in 1965. She was appointed an assistant professor at Boston University where she presented her ideas in a paper titled ''The Origin of Eukaryotic Cells.'' Her views were not well accepted by the biology community, and her paper was rejected by several scientific journals. However, in time, her insights were acknowledged and are now taught in high school biology classes. She was appointed a distinguished professor in the Department of Geosciences at the University of Massachusetts in 1988. Margulis was inducted into the World Academy of Art and Science, as well as the Russian Academy of Natural Sciences, and the American Academy of Arts and Sciences during the late 1990s. In 1999 she received the National Medal of Science Award. Along with several other scientists she has publicly expressed her doubts that HIV causes AIDS. In a July 2006 book review (on *Oncogenes, Aneuploidy, and AIDS* by Harvey Bialy) that she coauthored with her colleague James McAlllister and which appeared on Amazon.com, she claimed this connection is based on moralizing and obfuscation and that though this approach to the viral infection may make for ''good marketing,'' it is not based on good science. She is also interested in *autopoiesis,* which is the physiological outlook as an alternative to what is known as mechanistic neo-Darwinism, and James Lovelock's theory of *Gaia* that claims that ''Mother Earth'' is regulated by life and its environment.

Lynn Margulis based her theory on the work and concepts of **symbiosis** proposed by other scientists in the late nineteenth and early twentieth centuries. Nevertheless, her theory of **endosymbiosis** was the first to be based on direct microbiological observation, whereas earlier versions were based on biological and zoological observation. Biological observation at the microscopic level led to greater understanding of the new field of evolutionary biology. Margulis' theory posits that about 3.5 billion years ago ancient bacteria-like **prokaryotes** (cells that had no nuclei or membrane surrounding them) were somewhat diversified in functions. Through a symbiotic process of cooperation, these ancient bacteria cells combined with larger cells and became modified with a membrane that surrounded internal structures, known as the genetic material of **mitochondria**, chloroplasts, and other inner cell particles. The nucleus was also surrounded by a membrane, thus forming a new organism, namely, the more advanced **eukaryotic** cells with their own DNA that became more diverse in their functions and became the driving force of evolution. Margulis' endosymbiotic theory is impelling current concepts about the human genome as major portions of this genome (DNA) originated either from bacteria or viral sources—some of these sources were ancient, others more modern. This symbiotic, or possibly parasitic, relationship is being investigated as the driving force for genetic change in all organisms, including humans. In summary, Margulis' theory states that the development of eukaryotic cells are a symbiotic combination of primitive prokaryotic cells.

MARTIN'S THEORY OF CHROMATOGRAPHY: Chemistry: *Archer John Porter Martin* (1910–2002), England. Martin and his colleague the British biochemist Richard L.M. Synge shared the 1952 Nobel Prize for Chemistry.

A mixture (solution) of different chemicals can be separated and analyzed according to their differences in partitioning behavior between either a mobile phase or a stationary phase based on the components of the mixture's electric charge, relative absorption rate, or degree of solubility.

Archer Martin did not actually invent the original technique for chromatography. Rather, it was the Russian botanist Mikhail Semyonovich Tsvet (1872–1919) who discovered the technique as he was researching the composition of chlorophyll in 1901. Tsvet used a liquid-adsorption column to separate different pigments from green plants by using calcium carbonate, but he had no idea of how the physical process of chromatography worked. That honor goes to Archer Martin and Richard Synge (1914–1994) who were jointly awarded the 1952 Nobel Prize in Chemistry for their theory explaining the partition method of separating different molecules by utilizing the basic concept of a *mobile phase* and *stationary phase* for the original paper form of chromatography. There are two major theories of chromatography, the *plate* and *rate* processes.

The *rate theory* is based on the speed at which a substance is retained as it moves in a chromatographic system. It can be expressed by the equation:

R_f (Rate or Retention Factor) = Distance the sample is moved by the compound used in the solvent divided by the distance the sample is moved by the solvent.

The other theory is called the *plate theory*. Its equation follows:

K (the partition coefficient) = Concentration of the solute in the stationary phase divided by the concentration of the solute in the mobile phase.

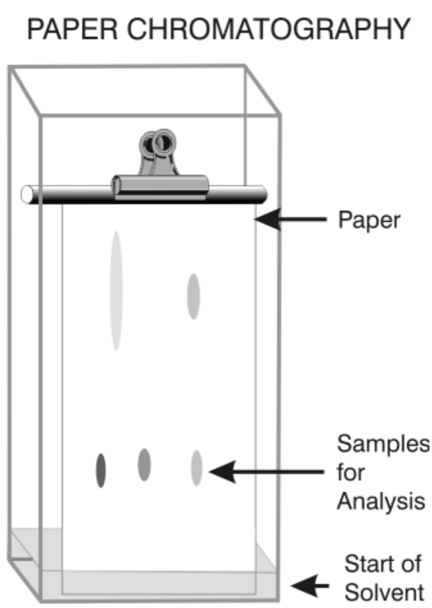

Figure M1. The movement of the samples on the paper determines the rate factor that is compared to a standard used in testing the sample.

Some examples of techniques for separating very different molecules, as well as procedures for separating even very similar molecules, follow.

1. *Paper chromatography* is an original technique where a sample in a solution phase is placed onto a strip of special chromatography paper. The paper is placed on end in a jar with a shallow pool of the solvent. The jar is then sealed to prevent evaporation of the solvent that rises through the paper to meet the sample mixture that travels up the paper along with the solvent. Different molecules of the sample travel different distances up the paper according to their molecular composition. The amount of movement of the components of the sample determine the rate or retention factor as expressed in the above equation, and thus can be compared to a standard that assists in the identification of the unknown sample being tested.
2. *Column chromatography* utilizes a vertical glass column filled with a silica-gel-type of permeable solid as the support to prevent the liquid sample from flowing too freely down the column. The sample

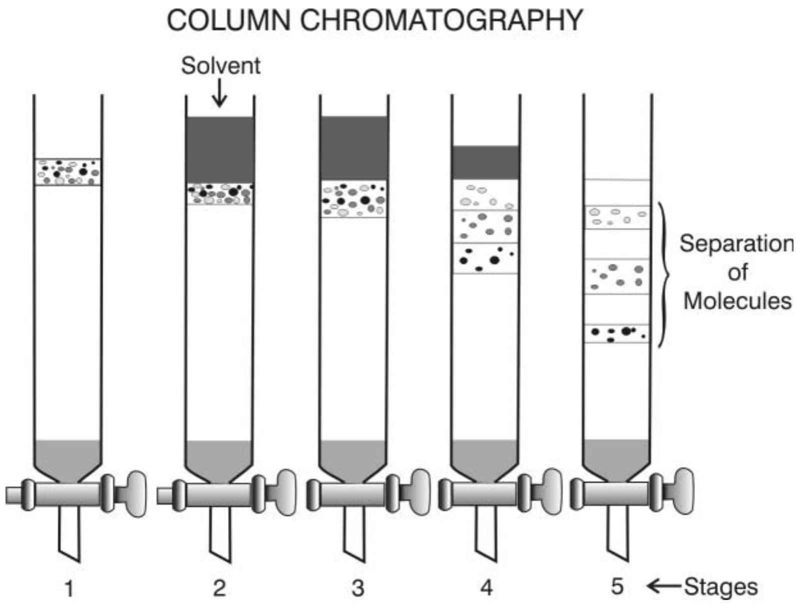

Figure M2. There are several versions of column chromatography that compare the rate of separation of the various molecules as does paper chromatography, but is faster.

to be tested is placed on top of this support substance and a liquid solvent is placed at the top of the column. Gravity moves the solvent vertically along with the sample downward at different rates through the medium and is collected at different exit rates from the column for analysis using the K (partitioning coefficient) equation. There are a number of versions of this technique, including one called "flash column chromatography" where the solvent is driven through the column by applying pressure on it.

3. *Thin layer chromatography* is similar to paper chromatography but involves a different type of stationary phase than paper. A thin layer of absorbent-like silica-gel or cellulose is coated on a flat inert surface. It provides faster "runs" of samples than regular paper chromatography.
4. Other types of chromatography are high performance liquid chromatography; ion exchange chromatography, size exclusion chromatography; affinity chromatography; gas-liquid chromatography; countercurrent (liquid-liquid) chromatography; centrifugal partition chromatography; several variations of the above are also used to analyze specific types of molecules.
5. A similar analytical technique is called *electrophoresis* (*Electro* = "energy" and *Phoresis* = "to carry across"). It is used to separate macromolecules of proteins and DNA based on their size and the inherent small electric charge on molecules. The process uses a small electric charge across a colloidal gel with the negative pole at one end of the gel and the positive pole at the other. The test molecules are placed in the gel and forced across a span of the gel by the electric charge. The molecular particles with a slight positive charge (+ cations) are attracted to the negative end of the gel substrate while the molecules with a slight negative charge (anions) are attracted to the positive end. This method is

used for analyzing amino acids, peptides, proteins, nucleotides, and nucleic acids (DNA).

MATTHIAS' THEORY OF SUPERCONDUCTIVITY: Physics: *Bernd Teo Matthias* (1918–1980), United States.

Superconductivity of a material depends on the number of outer electrons on the atoms of that material.

Bernd Matthias was born in Frankfort, Germany, at the end of World War I. His father died when he was young, but his mother was a lifelong influence on his career by creating a free intellectual and forgiving atmosphere that influenced his approach to scientific research and his lifestyle. At the age of fourteen his mother, sensing the coming rule of the Nazis, sent him to college in Switzerland. He later received his PhD degree in 1943 from The Federal Institute of Technology in Zurich, Switzerland. He emigrated to the United States in 1947 where he spent some time at Massachusetts Institute of Technology (MIT) and soon after moved on to Bell Labs in Murray Hill, New Jersey. From there he spent a year at the University of Chicago experimenting with the techniques of low-temperature physics. Matthias was an unusual experimental physicist whose discoveries were based on experimentation rather than on theory. He believed that no theorist ever predicted the existence of a new superconductor. His unusual techniques and personality led some theoretical physics to disparage his method as ''schmutz'' physics, meaning ''dirty physics.'' He was also called an ''alchemist,'' a reference to the ancient philosophers/scientists who believed in the ''philosophers' stone'' and the transmutation of base metals (*see* Paracelsus). Matthias relished this association as a modern-day alchemist because he loved to prepare and experiment with new materials and to explore their potential as low-temperature superconductors. One reason for his success was that intuitively he used Mendeleev's **Periodic Table of Chemical Elements** to assist in his discovery of different materials, and he attributed his many discoveries to this intuition as well as an understanding of the simplicity of nature. He is said to have commented that if a physics formula was over one-fourth of a page long, to forget it; it is wrong because nature is not that complicated. He enjoyed the process of discovering anything new in physics, particularly if it was not based on theory. During his lifetime he was the leading discoverer of cooperative phenomena in solid materials, particularly crystals.

Bernd Matthias' theory related to attempts to cause the electrons located on the outer shell (orbit) of atoms, or even free electrons, to flow as an electric current without resistance at temperatures much higher than absolute zero. This is known as superconductivity, and it occurs when the electrical resistance of a solid disappears as it is cooled to the "transition temperature," which for most metals and alloys takes place below 20 kelvin (K) or about −253°C. In 1911 Heike Kamerlingh-Onnes, when liquefying helium, also discovered that mercury, the only metal existing in a liquid state at room temperature, became superconductive at about 4 K (−269°C). At normal room temperatures, electrons in metal conductors collide as they flow through wire, causing a resistance to the flow of electrons (current). Thus, the wire heats up (as in the filament of an incandescent light bulb). What caused supercooled metals to lose their resistance to electricity was not known until the early 1950s, when Matthias began experimenting with various metals and alloys. By observing the behavior of several samples, he determined the number of electrons in the outer orbit of atoms was one factor and the crystalline structure of the material was another. Matthias made a compound of niobium and germanium (Nb_3Ge), which became superconductive at the unexpected high temperature of 23 K. Since then, physicists have attempted to determine the transition temperatures of numerous alloys and compounds, thereby causing superconductivity at much higher temperatures, because cooling to near absolute zero K is extremely difficult and expensive. Because liquid helium is used to cool metals to near absolute zero, its use is limited to small applications (e.g., cooling MRI supermagnets). Experiments were conducted using the less expensive element nitrogen, which becomes liquid at −196°C, instead of helium. Several ideas have been proposed to develop high-temperature superconductivity. One is to work with films of newly developed materials that can pass on free surface electrons with little or no resistance to the flow of current. A possible application of the film technique is a high temperature superconductor for computer switches and components that can run exceedingly fast without producing much heat. Reports of the discovery of so-called high-temperature superconductivity are very promising, but not yet confirmed. One goal for the future is the development of low-cost electrical transmission lines without the conversion of electricity to heat caused by resistance within the wires. Another is to use supercooled magnets to levitate magnetically driven trains.

See also Kamerlingh-Onnes

MAUNDER'S THEORY FOR SUNSPOTS' EFFECTS ON WEATHER: Astronomy: *Edward Walter Maunder* (1851–1928), England.

When there is a minimum of observed sunspots, there is a corresponding long, cold period on Earth.

While examining ancient reports of dark spots on the sun by astronomers, Edward Maunder realized there were no reports of similar activity on the surface of the sun for the period from the mid-1600s to the early 1700s. It was also determined, from other reports, that this was a period during which Earth experienced lower temperatures than usual. Using this material, Maunder developed a statistical analysis demonstrating that when there is a dearth of sunspots, a prolonged cold spell on Earth occurs. Maunder's "minimum" is still used along with more sophisticated techniques to aid in determining long-term climate changes on Earth. Current theories related to climate change are more concerned with the warming of Earth rather than the cooling correlation with sunspots. Currently, the tendency is to attribute global warming and the one-degree centigrade increase in global temperature over the past century to human behavior, activity, and resource consumption. Not all computer programs designed to determine causes of global warming include all the possible variables that affect global temperatures. It is not always recognized that Earth has gone through many short and long periods (cycles) of cooling and warming in past centuries. The global warming dilemma requires less politics and more science before the problem is completely understood.

MAUPERTUIS' PRINCIPLE OF LEAST ACTION: Physics: *Pierre-Louis Moreau de Maupertuis* (1699–1759), France.

Nature chooses the most economic path for moving bodies.

Pierre-Louis Maupertuis' principle of least action was a forerunner of all later theories and physical laws dealing with conservation, such as the conservation of energy and the concept of entropy. Maupertuis conceived this principle to explain the path that light rays travel, but it seemed applicable to all types of moving bodies. It basically states that nature will take the easiest, shortest route to move things from one point to another. Maupertuis was also interested in applying this principle as a means of unifying all the laws of the universe and thus arriving at proof for the existence of God. Maupertuis' principle was widely applied in the fields of mechanics and optics. A similar principle was proposed by Leonhard Euler in his form of calculus dealing with mathematical variations. Pierre de Fermat also used Maupertuis' principle to describe how light is refracted according to Snell's law, which states that light takes the least time possible when traveling from a medium of one density to a medium of a different density.

Maupertuis also theorized in areas of evolution with his study of the nature of biparental heredity. He based his theory on his detailed study of the occurrence of polydactyly (extra fingers) on several generations of a family in Berlin. He determined that the polydactyly trait was a mutation and could be transmitted by either the male or female parent to offspring. He was able to determine the mathematical probability that the trait would occur in future members of families afflicted with this anomaly. This was the first scientifically accurate record for the transmission of a hereditary trait in humans. He also wrote a book based on his microscopic examinations of embryos in which he challenged Jan Swammerdam's theory of "preformation." This discredited theory states the germ cell (gamete), either the ovum or sperm, contains a tiny homunculus of a human figure. Those who believed that it was the female gamete egg cell (ovum) that contained a fully formed organism of its kind are known as "ovists," whereas those who believed the homunculus is imbedded in the male gamete (sperm) are known as "spermatists." In either case, the tiny person (homunculus) does not start to grow until fertilization occurs. The development of the embryo involves merely an increase in size. In other words, prefomationists believed a homunculus, which is a tiny version of the adult, was housed in the germ cell, whereas Maupertuis argued that the embryo undergoes distinct stages of development as well as increases in size.

See also Euler; Fermat; Snell; Swammerdam

MAXWELL'S THEORIES: Physics: *James Clerk Maxwell* (1831–1879), England.

Maxwell's kinetic theory of gases: *All gases are composed of large numbers of particles (atoms or molecules), all of which are in constant random motion.*

James Clerk Maxwell determined that the stability of Saturn's rings could be explained only if the rings consisted of a multitude of very small solid particles, a theory that has been accepted ever since. From this reasoning, he formulated his kinetic theory of gases, which states that heat is the result of molecular movement. His theory is also accepted today with modifications that incorporate relativity and quantum mechanics. Maxwell realized he could not predict the movement of a single tiny molecule. But on a statistical basis, the laws of thermodynamics, first proposed by Nicolas Carnot, could be explained as molecules at high temperatures (rapid movement) having a high probability of movement in the direction of other molecules with less movement (lower temperatures). Maxwell and Ludwig Boltzmann arrived at a theory that relates the "flowing" motion of gas molecules to heat being in equilibrium. In other words a hot cup of coffee, if left sitting, will become cooler—never hotter unless more heat is added, and in time the coffee's temperature will be in equilibrium with

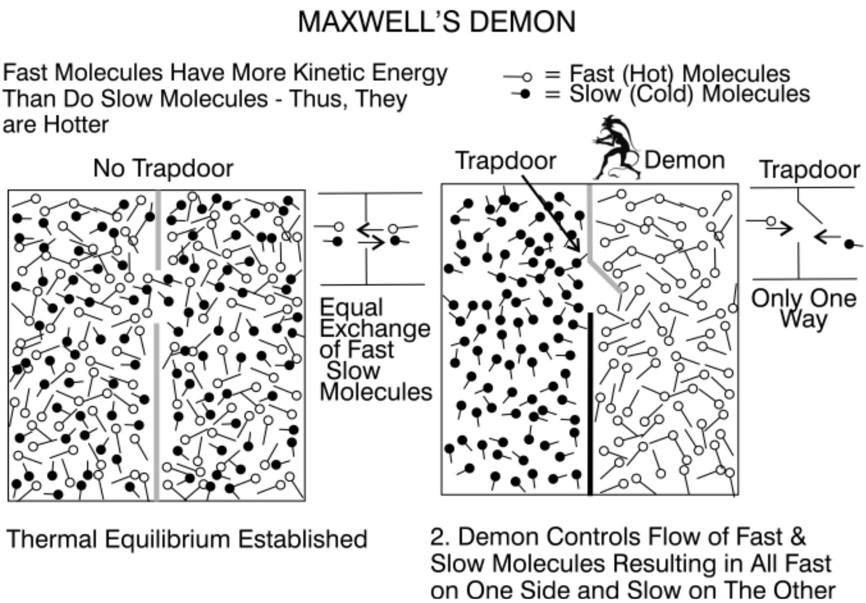

Figure M3. The demon allowed only fast molecules to collect on one side and slow molecules on the other side. Since no equilibrium is established between the two sides, the second law of thermodynamics is violated.

the temperature of its surroundings. Maxwell and Boltzmann also formulated a mathematical expression that indicated what fraction molecules had to a specific velocity. This expression is known as the Maxwell–Boltzmann distribution law (*see also* Boltzmann; Carnot).

Maxwell's demon paradox: *The demon is a tiny hypothetical entity that can overcome the second law of thermodynamics, thus making possible a perpetual motion machine (i.e., its energy will never escape into useless heat).*

James Clerk Maxwell's work with the kinetic theory of gases led him to speculate on what became known as his "demon paradox." He created his mythical demon from the Maxwell–Boltzmann statistical distribution law that describes the properties of large numbers of particles that, under certain statistical conditions, were inconsistent with the second law of thermodynamics. That is, heat does not flow from a colder body to a hotter body without work (energy) being expended to make it do so (e.g., an air-conditioner). Maxwell proposed an intellectual hypothesis where an **adiabatic** wall separates each of two sealed, equal-sized enclosed compartments (*see* Figure M3). The trapdoor separating the left and right sides of container number 1 is open and the molecules can freely go from side to side. Thus equilibrium is established, and the second law of thermodynamics is upheld. The trapdoor for container 2 is controlled by the "demon," which allows only fast (hot) molecules to enter the right side of the container and only slow (cold) molecules to go through the trapdoor to the left side (these are closed systems; no gas can enter or leave the boxes). The "presence" of the tiny "demon" that sits by the trapdoor in container 2 opens the door for molecules of specific high speeds to go in only one direction and the slow-speed molecules to only go in the other. The object of the experiment is for the demon to collect in container 2 all the faster/hotter (on the average) molecules inside the room on the right side and the slower/colder ones (on the average) in the room on the left side. The paradox is there are more fast-moving, hot gas molecules in one room than the other without the input of any outside energy. Thus, the concept of conservation of energy has been satisfied because no kinetic energy was lost, but the concepts of entropy and thermal equilibrium have been violated. However, in the demon's experiment, we now have imbalance of kinetic (heat) energy because the demon allowed only the high-energy (hot) molecules to go into one side of the number 2 container. This appears to be a violation of the second law of thermodynamics.

The paradox is resolved by recognizing that the demon is doing work by opening the doors and that he requires information about the speed of the molecules in order to open the door at the right time. The input of information is responsible for the decrease in entropy of the system. Thus, the second law of thermodynamics is not really violated. Of course, perpetual motion is unobtainable, but this was not understood until the laws of thermodynamics became known. Maxwell's treatment of entropy on a statistical basis was an important step in realizing that to obtain knowledge of the physical world, one must interact with it.

Maxwell's theory for electromagnetism: *Magnetism and electricity produce energy waves, which radiate in fields with differing wavelengths.*

Familiar with Michael Faraday's theories of electricity and magnetic lines of force and expanding on the mathematics developed by Faraday; Maxwell combined several equations that resulted in the establishment of direct relationships in the fields produced by magnetism and electricity and how together they affect nature. Once the equations for magnetic and electric fields were combined, he calculated the speed of their waves. Maxwell concluded that electromagnetic radiation has the same speed as light—about 186,000 miles per second. At first, Maxwell accepted the ancient concept of the existence of the aether in space. (It was thought that light and other electromagnetic waves could not travel in a vacuum; therefore the concept of "ethereal matter" in space was invented but never verified.) Maxwell believed electromagnetic radiation waves were actually carried by this aether and that magnetism caused disruptions to it. Later, in 1887, Albert Michelson demonstrated that any material body such as aether in space was unnecessary for the propagation of light. Maxwell's equations were still valid, even after the aether concept was abandoned. Maxwell concluded there were shorter wavelengths and longer wavelengths of electromagnetic radiation next to visible light wavelengths on the electromagnetic spectrum (later named *ultraviolet* and *infrared*). He further concluded that visible light was only a small portion of a "spectrum" of possible electromagnetic wavelengths. Maxwell then speculated and predicted that electromagnetic radiation is composed of many different (both longer and shorter) wavelengths of different frequencies. This concept developed into the electromagnetic spectrum, which ranges from the very short wavelengths of cosmic and gamma radiation to the very long wavelengths of radio and electrical currents (*see* Figure M4).

The theory of electromagnetic radiation is one of the most profound and important discoveries of our physical world. It has aided our understanding of physical nature and resulted in many technological developments, including radio, television, X-rays, lighting, computers, iPods, cell phones, and electronic equipment. Maxwell combined his four famous differential equations ("Maxwell's equations"). These four rather simple mathematical equations could be used to describe interrelated nature and behavior of electric and magnetic fields. They described the propagation of electromagnetic waves

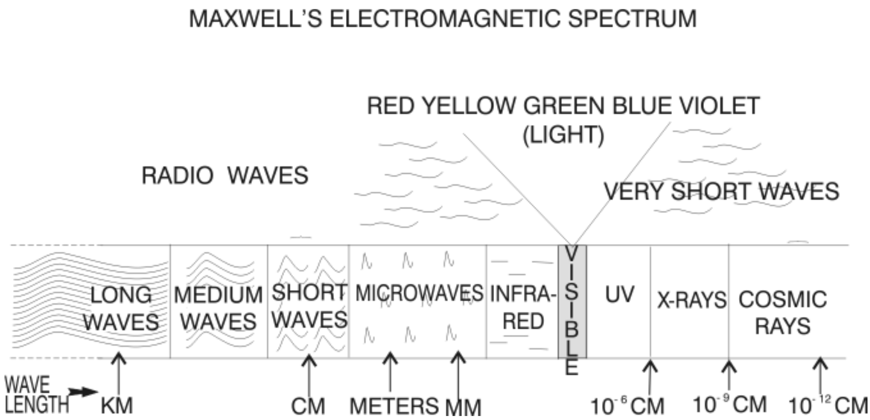

Figure M4. James Clerk Maxwell hypothesized the existence of electromagnetic radiation with longer and shorter wavelength than visible light that is located near the middle of the scale. This idea developed into the electromagnetic radiation spectrum for frequencies from very long radio waves to extremely short X-rays and cosmic radiation.

(radiation) in a form of the wave equation. This was the first time the constant for the velocity of light waves (c) was used; it later became an important constant in Einstein's theories of relativity and his famous equation, $E = mc^2$. Maxwell experimented in many areas, and his accomplishments were substantive, including an explanation of how viscosity of a substance varies directly with its temperature. Maxwell's contribution to the physical sciences was not only significant but his theories were among the few from his day in history that held up following the evolution in knowledge that began with the advent of the new science of relativity by Albert Einstein.

See also Einstein; Faraday; Michelson

MAYNARD SMITH'S THEORY OF EVOLUTION: Biology: *John Maynard Smith* (1920–2004), England.

Game theory is related to evolutionary stable strategies (ESS).

Maynard Smith formulated his theory of biological evolution by using concepts of the theory of games established by John von Neumann in the 1940s. The explanation follows: If there is competition between two animal societies, then an evolutionary stable strategy (ESS) occurs when a majority of that population prevents a mutant (different) strategy from invading the stable strategy. The odds are greater that a stable society of organisms will

John Maynard Smith borrowed the particular game theory often referred to as ''Hawk and Dove'' from the Pentagon that is sometimes utilized in the decision-making process to invade—or not to invade—another country. Maynard Smith related this game idea to evolutional survival odds to predict when an animal should fight to defend its territory and food supply, or when to hide or leave the territory. This theory was tested with various animals, including spiders, birds, and even humans. It concerns those that attack and those who defend a territory. When applied to evolution, the payoff in the game is reproductive fitness, whereas a loss is the potential reduction of reproductive fitness.

be a mixed society rather than a single (unmixed) society. Maynard Smith published his theory in a book titled *The Theory of Evolution* in which he presented the reasoning that supports and revealed the mechanisms of evolution. His application of game theory to evolutionary strategies added to a better understanding of the history of evolution. In 1982 he published *Evolution and the Theory of Games* describing the unusual game known as "Hawk and Dove" which is considered a classic theoretical game model. His theory of "ESS" is considered a division point between the old and more modern understanding of evolution.

Maynard Smith wrote in a clear and intelligent manner that even nonbiologists could understand. He was a good teacher who would take time to discuss his ideas with students and colleagues.

See also Von Neumann

McCLINTOCK'S THEORY OF CYTOGENETICS: Biology: *Barbara McClintock* (1902–1992), United States. Barbara McClintock received the 1983 Nobel Prize for Physiology or Medicine at the age of 81.

> *Genes can move around within cells and modify chromosomes, thus restructuring the genetic qualities of a species.*

Barbara McClintock's moving **genes** were referred to as "jumping genes" because they could transpose (change position or the order of genes) within chromosomes. She traced the evolutionary history of domesticated maize to determine the genetic ancestor of the grass we now know as corn. Much of her work was accomplished by using stains to aid in identifying the ten chromosomes found in maize (corn). These chromosomes were large enough to be viewed by a microscope, enabling her to identify and distinguish the different chromosomes from each other. By planting seeds from corn growing one year to the next, she tracked mutant genes over several generations. She found that in addition to single genes that were responsible for color (pigmentation) in the corn, she found groups of genes linked together that caused other mutations. She referred to these as "controlling elements," which dictated the rate for the on-off switching action of other genes. McClintock discovered that these controlling genes could move within a single chromosome, or they could "jump" to other chromosomes and control their genes. McClintock's work with genetics came just twenty years after Mendel's principles of heredity were accepted. She provided an extensive account of her theory of the process of "transporter" of genes in her 1951 paper "Chromosome Organization and Genic Expression" which was largely ignored. Although her work was ignored primarily because it was far advanced for the 1940s, this was also a period during which Mendel's principles of heredity were generally not understood and were also not generally accepted. McClintock's concept of groups of genes working together and controlling other genes came before the discovery of DNA that advanced our understanding of evolution. Today, we know that her work, although not recognized at the time of its discovery, explained one of the mechanisms of evolution.

See also Mendel

McMILLAN'S CONCEPT OF "PHASE STABILITY": Physics: *Edwin Mattison McMillan* (1907–1991), United States. Edwin McMillan shared the 1951 Nobel Prize for Chemistry with Glenn T. Seaborg.

Using variable frequencies of electrical impulses in a cyclotron, it is possible to compensate for the increase in mass of accelerating subatomic particles, thus increasing their speeds.

Edwin McMillan was aware of the problem that Ernest Lawrence's cyclotron experienced with the ever-increasing "speeds" obtained during acceleration of subatomic particles. According to Einstein's theory of relativity, the greater a particle's acceleration, the greater is its increase in mass. This is the reason why particles with mass can never reach the speed of light because the particle would become more massive than the entire universe—if there existed enough energy in the universe to accelerate it to such a velocity. Lawrence's cyclotron used a fixed frequency of electrical stimulation to accelerate the beta, alpha, or other subatomic particles. As these particles spun around, faster and faster in the cyclotron, they increased in mass and thus became out of phase with the frequency of the electrical impulse, which resulted in a limit to their speed. McMillan's solution was to use a variable frequency that could change as the mass of the particles changed. This led to a new device, the synchrocyclotron (also known as the synchrotron). It was so named because it could synchronize the frequencies required to maintain the increasing speed of the particles within the cyclotron to the regions of hundreds or even thousands of megaelectronvolt (MeV equal to 1,000,000 volts) and continue to accelerate them to even greater energies, thus enabling physicists to explore the "split" particles and radiation resulting from collisions between particles. McMillan and Seaborg shared the 1951 Nobel Prize for the isolation of the elements neptunium and plutonium.

See also Einstein; Lawrence; Seaborg

MEISSNER EFFECT: Physics: *Fritz Walther Meissner* (1882–1974), Germany.

The weak magnetic field decays rapidly to zero in the interior of a superconductor metal as the temperature reaches absolute zero.

Walther Meissner was a mechanical engineer known as a "technical physicist" rather than a "theoretical physicist." In the early 1930s he was working with the German physicist Robert Ochsenfeld (1901–1993) when they established the largest helium-liquefier (to achieve near absolute zero temperatures). They used this device to discover the damping (slowing down or reducing of an effect) of magnetic fields in superconductor materials. They unexpectedly discovered the phenomenon that became known as the "Meissner effect" when they realized that when adjacent large cylindrical crystals of tin had their temperatures reduced to 3.72 K (−452.97 F), their natural magnetic fields disappeared from their interior. This is their critical temperature point (Tc) and indicates the beginning of superconductivity as well as perfect diamagnetism (superconductivity occurs at temperatures that are near absolute zero). In other words, the magnetic flux is expelled from a superconducting metal when it is cooled in a magnetic field to below its critical temperature as the temperature approaches absolute zero and superconductivity is occurring. This discovery led to a deeper understanding of the laws of thermodynamics as well as establishing the theory of superconductivity and the theory of electrodynamics of superconductivity by the brothers Fritz London (1900–1954) and Heinz London (1907–1970), two German-born physicists.

It might be mentioned that later there were some limitations to the Meissner effect. First, the magnetic field is not totally expelled as the metal crystals are cooled, but rather a very thin layer remains on the surface where the current continues to flow. This thin surface layer "screens" the internal portion of the metal from the magnetic field, thus offering less resistance to the flow of current on the surface of the conductor. Second, the Meissner effect is not observed in impure samples, nor certain types of crystals, nor flat round discs of the metal.

MEITNER'S THEORY OF NUCLEAR FISSION: Physics: *Lise Meitner* (1878–1968), Austria. Lise Meitner received the 1966 Enrico Fermi Prize from the U.S. Atomic Energy Commission for her work on nuclear physics.

As the nuclei of uranium absorb neutrons, the nuclei become unstable and "fission" into two smaller lighter elements; in addition, they produce extra neutrons and radiation.

Lise Meitner, an Austrian physicist who emigrated to Sweden in the 1930s, collaborated with Otto Hahn on nuclear physics research. In 1938 Hahn and the German

Lise Meitner was an unusual woman who struggled all her life to make a scientific name for herself in an exceptionally patriarchal field. She was the first woman to enroll as a student in the University of Vienna in 1901. Early in her academic life she showed an interest in science and mathematics. Her first break came when she pursued these subjects under two great teachers, the famed Austrian physicist Franz Exner (1849–1926) and Ludwig Bolzmann. Meitner had great skills in these areas, and her doctoral dissertation was an unusual experiment related to one of the theories of James C. Maxwell. Because of her gender the only career open to her was teaching. Thus, she decided at the age of twenty-eight to move to Berlin, which was the center of physics explorations. She planned to spend a few years there but stayed over thirty years until 1938 when Germany no longer allowed Jews to enter professional positions. She became an assistant to Otto Hahn while in Berlin, but with no title and no salary. Together they became known as leaders in the transformation of one element into another and, in particular, the heavier elements that were radioactive. She formed friendships with Max Planck, Niels Bohr, Max Born, Wolfgang Pauli, James Chadwick, and Albert Einstein. Her work with the nuclei of uranium was based on James Chadwick's research and discovery of the neutron and Enrico Fermi's theory of shooting neutrons into the nuclei of atoms to explore their structure. Fritz Strassman, Otto Hahn, and Lise Meitner decided to bombard a sample of uranium with neutrons to study the radiation that resulted and to synthesize other elements. During the late 1930s it became too dangerous for her to remain in Germany, but the Nazis refused to issue her a passport. Because she was now a well-known physicist outside her native country, many people helped her to escape to Sweden. Dirk Coster (1889–1950), the Dutch physicist who held a prominent post at the Groningen University in the Netherlands was of particular assistance. She continued to collaborate with Hahn via the mail wherein he informed her that he and Strassman had created the radioactive isotope of barium. She and her nephew Frisch calculated that the process of "fission" should result in enormous amounts of energy. Hahn wrote up the results for publication, but they could not include her name as an author because she was a political refugee. Hahn soon disregarded Meitner's role in this discovery and thus she was not included in the 1944 Nobel Prize that was awarded to Hahn. Although they continued to write to each other, she was disappointed in not receiving credit for her work. Hahn and Meitner had a contentious relationship. She also was critical of him and other German scientists for their failure to confront the racial prejudices of the Nazis. Lise Meitner died at the age of 89 in 1968.

chemist Friedrich (Fritz or Fuzzy) Strassman (1902–1980) became perplexed when they "shot" neutrons into nuclei of uranium. To their amazement, the uranium nuclei became lighter rather than heavier when absorbing neutrons. Hahn contacted Meitner and requested assistance in solving this problem. In 1939 Meitner and her nephew Otto Frisch, who at the beginning of World War II escaped Germany to live in the Netherlands, solved the problem together. As the nuclei of uranium atoms absorb neutrons, their nuclei increased their atomic mass to the point that they become unstable due to the excess of neutrons. Each of the unstable uranium nuclei undergoes fission (splitting) into two smaller fragments of almost the same size. While the uranium nucleus is splitting, at the same time it ejects two or three other free neutrons as well as energy in the form of radiation. Frisch named this process *fission*, after the process that cells undergo when dividing. It was never understood why Meitner and Frisch were never recognized for the importance of their discovery of a chain reaction of fissionable unstable uranium nuclei for the production of energy (Otto Hahn received the 1944 Nobel Prize for Chemistry, Not long after, this concept was used by the United States to develop the atomic bomb.

See also Chadwick; Fermi; Frisch; Hahn

MENDELEEV'S THEORY FOR THE PERIODICITY OF THE ELEMENTS: Chemistry: *Dmitri Ivanovich Mendeleev (also spelled Mendeleyev)* (1834–1907), Russia.

> *There is a definite repeating pattern of the properties of elements based on the elements' atomic weights and valences.*

MENDELEEV'S PERIODIC TABLE OF THE CHEMICAL ELEMENTS

TRANSITION ELEMENTS

GROUPS / PERIODS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1	1 H 1.0079																	2 He 4.00260
2	3 Li 6.941	4 Be 9.01218											5 B 10.81	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.9984	10 Ne 20.179
3	11 Na 22.9898	12 Mg 24.305											13 Al 26.9815	14 Si 28.0855	15 P 30.9738	16 S 32.066(6)	17 Cl 35.453	18 Ar 39.948
4	19 K 39.0983	20 Ca 40.08	21 Sc 44.9559	22 Ti 47.88	23 V 50.9415	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.80
5	37 Rb 85.4678	38 Sr 87.62	39 Y 88.9059	40 Zr 91.224	41 Nb 92.9064	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.906	46 Pd 106.42	47 Ag 107.868	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.75	52 Te 127.60	53 I 126.905	54 Xe 131.29
6	55 Cs 132.905	56 Ba 137.33	★	72 Hf 178.49	73 Ta 180.948	74 W 183.85	75 Re 186.207	76 Os 190.2	77 Ir 192.22	78 Pt 195.08	79 Au 196.967	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.980	84 Po (209)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra 226.025	▲	104 Unq (261)	105 Unp (262)	106 Unh (263)	107 Uns (264)	108 Uno (265)	109 Une (266)	110 Uun (267)	111 Uuu (272)	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

6 ★ Lanthanide Series (RARE EARTH)	57 La 138.906	58 Ce 140.12	59 Pr 140.908	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.925	66 Dy 162.50	67 Ho 164.930	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.967
7 ▲ Actinide Series (RARE EARTH)	89 Ac 227.028	90 Th 232.038	91 Pa 231.036	92 U 238.029	93 Np 237.048	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

Figure M5. Mendeleev's Periodic Table of the Chemical Elements was originally organized according to atomic weights and chemical characteristics. It was later revised based on atomic numbers instead of weights.

Dmitri Mendeleev was not the first to recognize some sort of pattern related to similar characteristics of elements based on their atomic weights, atomic numbers, or their ability to combine with each other. Several chemists recognized that elements seemed to be grouped in triads, or in repeating groups of seven, or with some evidence of "octave" periodicity of their properties (*see* Figure N2 under Newlands). In 1870, one year after Mendeleev published his **Periodic Table of the Chemical Elements**, Julius Meyer conceived a table similar to Mendeleev's. Meyer plotted a chart relating physical and chemical properties of elements with their atomic weights. His work, however, was overshadowed by Mendeleev's publication in 1869. Mendeleev classified the elements by their atomic weights as well as valences, even though some of the valence numbers for the elements conflicted with the arrangement of the atomic weights (*see* Figure M5). He realized after a row of seven there must be another column to complete that segment, so that a new row, based on continuing periodicity of atomic weights, could be recognized in the organized chart (the octet or rule of eight). Mendeleev exhibited great insight by "skipping places" in his periodic table for elements not yet discovered. He called the yet-to-be-discovered elements *eka* (meaning "first" in Sanskrit) elements, which he predicted would fit the blank spaces he provided in his table by predicting atomic weights and properties.

It was later discovered that the few inconsistencies in Mendeleev's periodic table were due to the use of atomic weights instead of atomic numbers (the number of protons in the nucleus). Once this was corrected, the current periodic table proved to be not only one of the most useful but also one of the most elegant organization charts ever conceived.

See also Cannizzaro; Dobereiner; Frankland; Meyer; Newlands

MENDEL'S LAW OF INHERITANCE: Biology: *Gregor Johann Mendel* (1822–1884), Austria.

Characteristics of offspring are determined by two factors, one from each parent.

Gregor Mendel entered the Augustinian monastery at Brünn, Austria, in 1843 where he continued his childhood interest in horticulture that led to his study of the role of hybrids as related to evolution. He was a meticulous experimenter, who began by keeping records of as many as seven different characteristics of parent pea plants in succeeding generations. He was interested in the ratio of specific characteristics that passed from parent plants to offspring plants (*see* Figure M6). He calculated ratios for the inheritance of stem length, the position of the flower on the stem, the color of the unripe pads, the smoothness and roughness of the pea pods, color of seeds, forms of seeds, and cotyledon (seed coat) color.

His work, although not recognized at the time he made his observations, was the first to provide a mathematical basis to genetics. From his observations and calculations, he based his law of inheritance on three theories:

1. As the female parent's egg and male parent's sperm sex cells mature, the formerly paired inheritance factors divide, resulting in just one specific factor for each characteristic from each parent. These single factors are then combined into a new pair during fertilization and are responsible for the inherited characteristics of the offspring. This is now known as the principle of *segregation*.

2. Characteristics are inherited individually. This means that one factor or characteristic can be inherited along with another factor and may be either dominant or recessive (e.g., tall stems with wrinkled pea pods). This is known as the principle of *independent assortment*.
3. Each characteristic is the result of the connection of at least two genes, one from each parent. One of these two factors is always dominant over the other. This is now known as the *law of dominance*.

Mendel's law indicated there was not a blend of inherited characteristics, but rather "fractional" inheritance, which strengthened Darwin's concept of natural selection. Later in life, in 1868 he became the abbot of a monastery, thus reducing time he could devote to his research. It would be many decades later before the value of his work would begin to be appreciated.

See also Darwin; De Vries

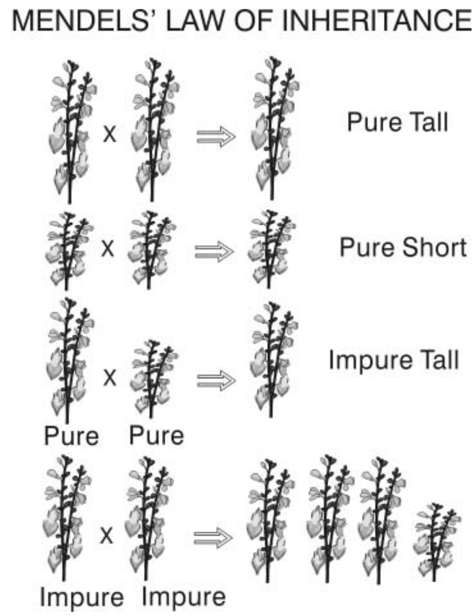

Figure M6. Mendel studied the ratios of plant characteristics to determine the rate of inheritance of these characteristics.

MERRIFIELD'S THEORY OF SOLID-PHASE PEPTIDE SYNTHESIS: Biochemistry: *Robert Bruce Merrifield* (1921–2006), United States. Robert Bruce Merrifield was awarded the 1984 Nobel Prize for Chemistry.

An excess of reagents can wash chains of peptides composed of amino acids to accelerate the removal of side chains and thus protect the peptide molecules.

Peptides are organic compounds in which multiple amino acids are bonded by peptide bonds, also known as amide bonds. To artificially synthesize peptides it is necessary to join carboxyl groups of one amino acid to other groups of amino acids, using one of two methods: *liquid-phase synthesis* and the *solid-phase peptide synthesis*, known as SPPS.

Robert Merrifield began work on his concept of the SPPS method of peptide synthesis in 1950s. Note: Peptides are similar to proteins but are composed of shorter and less complicated chains of molecules that are mostly proteins. Merrifield realized that if peptides could be synthesized by using less expensive and more rapid methods rather than those that employ complicated laboratory procedures and take months to accomplish, the process could be used to produce many useful commercial and medical products. He experimented with over one hundred different substitute resins and eventually invented a method that applied an ion-exchange process of bonding the amino acids to the insoluble solid support of a polystyrene resin. The beauty of this innovation of using insoluble resins was that it provided a solid support when different solvents were used to wash away impurities. These resins provide a means of introducing an amino acid by the methods of substitution, condensation, or addition-type reactions. In 1964 Merrifield was successful in synthesizing a nine-amino acid peptide that was effective in dilating blood vessels. The steps in this process are many and lengthy—over five thousand steps are involved in forming the final peptide chain. Fortunately, Merrifield and others found a way to automate this process by using a continuous flow method for the reagents that pass through the reaction chamber that hold the resins and peptides. The reagents can "wash" the contents within the chamber and be recycled and used over many times. Using these automated procedures Merrifield was able to synthesize insulin in 1965. The other method of synthesizing peptides, known as the *liquid-phase synthesis* procedure, is the classical approach to accomplishing peptide synthesis. However, today it is only used for large-scale production of industrial-type peptides. Most laboratories prefer the faster, automated Merrifield SPPS method. Merrifield was awarded the 1984 Noble Prize for Chemistry for his work with peptide synthesis.

MESELSON–STAHL THEORY OF DNA REPLICATION: Biology: *Matthew Stanley Meselson* (1930–), United States.

The DNA double-helix molecule replicates, splits, and recombines to repair cells.

Matthew Meselson and the American molecular biologist Franklin Stahl (1929–) demonstrated that when "semiconservative replication" of DNA (deoxyribonucleic acid) takes place and divides into two new DNA cells, the double helix is also duplicated. The semiconservative aspect of their discovery was accomplished by using the common Escherichia coli cells grown in the presence of the isotopes of nitrogen. A batch of DNA and E. coli was grown in an environment of the isotope nitrogen-15 (^{15}N). This batch was then exposed to normal nitrogen-14 (^{14}N). Meselson and Stahl then used mass centrifuging to separate the two different weight isotopes by their slightly different densities. When reviewing the results, they discovered three different types of DNA, one type contained the N-15, another type had the N-14, and yet a third type was a hybrid containing equal amounts of the isotopes N-15 and N-14. When the hybrid double strand was heated and the two strands separated, it was found that each single strand could act as a template to form a similar type strand when replicated. The results of their study were published in the *Proceedings of the National Academy of Sciences* in the United States under the title, "The Replication of DNA in Escherichia coli," in 1958.

A few years later in 1961 several researchers used this information to develop more theories related to DNA. It was discovered that RNA and mRNA molecules are stable and serve as a "primer" for DNA that requires a small piece of a new strand so it can complete its synthesis. (RNA is a single strand of nucleic acid that provides instructions in the DNA nucleus and translates this information for the assembly of proteins in the cells.) In other words, for the DNA to replicate, it needs "information" from the RNA molecules to make the correct type of protein cells rather than some foreign cell. It was James Watson and Francis Crick, the discoverers of the double-helix structure of the DNA molecule, who predicted that one strand of the double-helix molecule came from a parent whose DNA was most recently duplicated.

See also Crick; Franklin (Rosalind); Miescher

MESMER'S THEORY OF ANIMAL MAGNETISM: Medicine: *Franz Anton Mesmer* (1734–1815), Austria.

The behavior of all things—all living organisms, as well as the heavens, Earth, moon, and sun—are affected by a ''universal fluid'' that can be received, propagated, and communicated with each other through motion.

Franz Mesmer based his theory on the three laws of motion as explained by Sir Isaac Newton. He believed that because the moon and sun cause tidal movements, their motions would also cause any earthly object, including humans, to affect each other through some unexplained "universal fluid." As a physician, he applied this theory of fluids and motion to treating patients with magnets, with the idea that the magnets might influence the "fluids" as they do metal. He soon found that the magnets were not needed if the patient was open to his suggestions of how to be "cured." His ideas were not well accepted in France in the late 1700s and resulted in a report on his methods by several scientists who investigated Mesmer's claims. This report stated that magnetism had no medical effect, that Mesmer's "suggestions" seemed to produce nothing but odd behavior in his patients, and a cure with magnetism without imagination did not exist. (This "myth" still exists as some entrepreneur "hucksters" claim that their magnetic devices can cure almost any illness. There is no scientific evidence that "magnetic therapy" is an effective cure for anything except the lack of income of the seller.) Nevertheless, "mesmerism" later became recognized as hypnotism, which was separated from the original discredited concept of animal magnetism. Although Mesmer's theories are no longer considered valid, his legacy remains when someone claims to be "mesmerized" or hypnotized. Hypnotism may affect a person's behavior, but it has never been proven to cure a disease caused by a bacterium or virus. Mesmer's concept of using magnets to cure all types of human ailments has been modernized and is considered by some as a form of alternative medicine, whose efficacy is yet to be proven.

METCALFE'S LAW: Computer Science: *Robert Melancton Metcalfe* (1946–), United States.

Metcalfe's law, which is related to the field of computer and telecommunications networks, states: *The value of telecommunications network technologies, such as the Ethernet and Worldwide Web, is proportional to the square of the number of users of the system represented by* n^2.

Robert Metcalfe was born in Brooklyn, New York, in 1946 at the beginning of the computer technology age. He graduated with two bachelor's degrees from the Massachusetts Institute of Technology (MIT) in 1969, one in electrical engineering and the other in management from MIT's Sloan School. He then attended Harvard graduate school, earning a master's degree in 1970 followed by a PhD in mathematics in 1973. Although he is involved in many enterprises, Metcalfe is best known for inventing the Ethernet, which is a standard for connecting computers over short distances. His law is responsible for the rapid growth of the Internet, particularly for the Worldwide Web of the Internet.

Metcalfe's law can also be expressed in two ways: 1) The number of possible cross-connections in a network increases as the square of the number of users (computers or other sending-receiving devices) in the network increases. And 2) the value of the network to the total community increases as the number of network users increases. Another way of saying this is: The power of a computer network increases exponentially with the number of computers (or other devices) that are connected to it (*see* Figure M7).

Along with Moore's law that is related to the power of computers (i.e., the number of transistors on an integrated circuit doubles every two years), Metcalfe's law explains the rapid growth of the Internet and the Worldwide Web. Together these two laws

EXAMPLES OF INTERCONNECTED NETWORKS

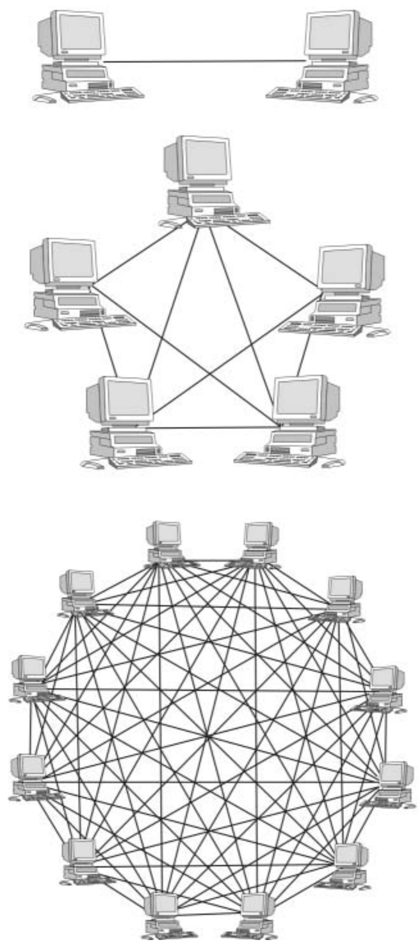

Figure M7. The power of a particular device connected to an interconnected network increases exponentially by the number of similar devices connected to it.

explain the tremendous increase in informational technology in the last quarter of the twentieth century that continues seemingly unabated.

Metcalfe's law has been challenged because it assumes that all connections to a network by all groups are of equal value. If this law was actually applied universally, it would be a great incentive for all networks to use the same technology and merge. However, this is not the way the open market operates. Metcalf's law has been revised to reflect this reality. It now states that the value of a network with n members is not n squared, but rather n times the logarithm of n. This revision states that the value of merging networks is not 100% as predicted by n^2 and, thus, is more indicative of what happens in real life.

Robert Metcalf is a general partner at Polaris Venture Partners and is a board member of many technology-oriented companies.

See also Moore

MEYER'S THEORY FOR THE PERIODICITY OF THE ELEMENTS: Chemistry: *Julius Lothar Meyer* (1830–1885), Germany.

There are step-wise changes in the valences of elements as related to their atomic volumes and weights.

Familiar with the work of Stanislao Cannizzaro who related Avogadro's number to the atomic weights of elements, Julius Meyer measured the volume and atomic weights of elements and plotted the results on a graph (*see* Figure M8).

In 1864 Meyer recognized that plotting the values of atomic volume against the atomic weight of elements would produce a graph indicating definite peaks and valleys, which related to the physical characteristics of different elements. Several examples of these peaks of plotted data were exhibited by the alkali metals, such as hydrogen, lithium, sodium, potassium, rubidium, and cesium, and one element not known at that time, francium. One of the most striking examples of periodicity based on properties of the elements was the series of sharp peaks representing the alkali metals. The alkali

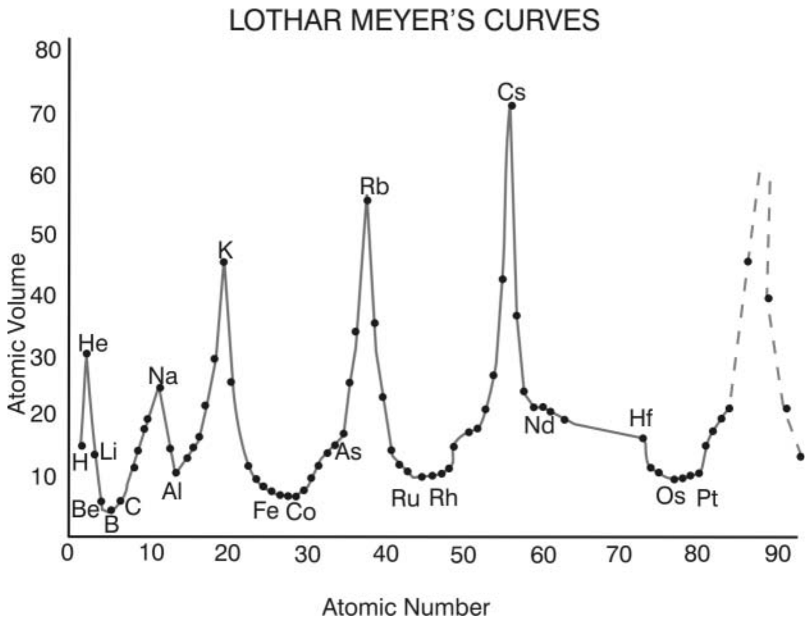

Figure M8. Lothar Meyer plotted the atomic volume against the atomic weights of atoms that results in "peaks" in the graph that relate to the physical characteristics of the different elements.

metal elements not only showed the beginning of a period but also had the greatest volume of the elements in their particular period. He also related the valences of elements that appeared at similar points on the graph to their chemical characteristics. This graph, referred to as *Lothar Meyer's curves*, was, in essence, the basis for the modern **Periodic Table of the Chemical Elements** (*see* Figure M4 under Mendeleev). Unfortunately, Julius Meyer did not publish his work until 1870, one year after Dmitri Mendeleev published his periodic table.

See also Avogadro; Cannizzaro; Mendeleev; Newlands

MICHELSON'S THEORY FOR THE "ETHER": Physics: *Albert Abraham Michelson* (1852–1931), United States. Albert Michelson was awarded the 1907 Nobel Prize in Physics.

> *If there is an aether, then the speed of light from space traveling directly toward Earth should be less as Earth moves toward the light source. Also, the speed of light traveling at right angles to Earth's motion should be greater than the speed of light coming toward Earth.*

The ancient concept of an **aether** (or ether) was used to explain the existence of some kind of matter in outer space because a pure vacuum was thought to be impossible. Because ancient scientists believed that nature abhors a vacuum, there must be some type of "matter" in space rather than a vacuum. More recently, the aether was considered as something beyond Earth's atmosphere that could carry electromagnetic

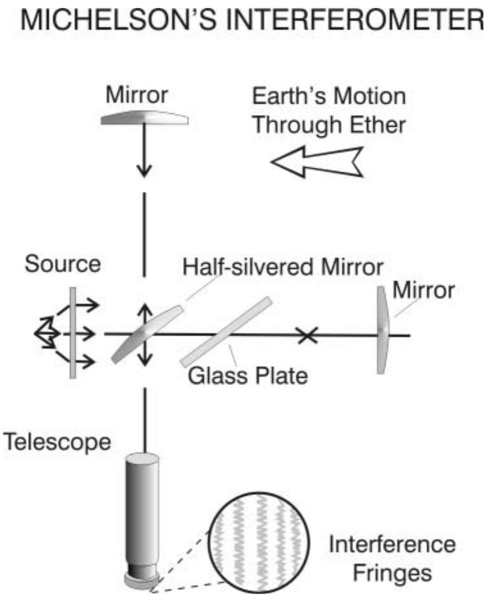

Figure M9. A diagram of Albert Michelson's interferometer designed to determine if an ether (aether) existed in space. If so, it might be detected by comparing a split beam of light as the Earth moved through this hypothetical space medium.

waves (light, radio waves, etc.), similar to how air molecules carry sound waves. Along with his colleague, the American scientist Edward Morley (1838–1923), at Western Reserve College (now Case Western Reserve University) in Ohio, Albert Michelson invented an instrument called the interferometer, designed to split a beam of light by using a half-silvered mirror, which allows half of the light from a source to be transmitted and the other half to be reflected. Each split beam then proceeded to separate mirrors arranged on arms of the apparatus, so that the split beams were again combined at the point at which they would interfere with each other to produce a characteristic pattern of fringes (*see* Figure M9).

The type of patterns formed depended on the time it took for each of the two beams to complete the trip from the source, through the split mirror, and return. The apparatus could be adjusted so that the light could approach at 90°, which then should produce a different fringe pattern. Because it was believed that the aether had no motion, as Earth moved through the aether (as sound moves through air molecules), the light coming directly toward Earth would be slower than the light coming toward Earth at a 90° right angle. After many repeated experiments using this interferometer, Michelson found no difference in the speed of light with his instrument despite the direction from which the light's speed was measured. This was the death knell for the aether concept. Michelson also used his interferometer to measure the diameter of various bodies that could be viewed with telescopes. He did this by comparing the light emitted from both sides of the planets and stars he observed. He continued his research on the speed of light and believed that the figure for the speed that light travels should be used as the standard for measuring length of objects and distance instead of the platinum meter stick that was then kept in Paris, France. This idea was adopted in 1960 when the wavelength of light from the inert gas krypton was accepted as the standard measure instead of the metric meter.

See also Einstein

MIESCHER'S NUCLEIN THEORY: Biology: *Johann Friedrich Miescher* (1844–1895), Switzerland.

Independent animal cells found in the pus from open wounds can be separated into proteins and acid molecules.

Using discarded bandages that contained yellow pus that oozed from healing wounds, Miescher filtered the viscous substance and discovered that it could be separated into independent animal cells (proteins and acid molecules).

He isolated a material that he called "nuclein," which today is known as DNA. Miescher was an eager young researcher hired by the German physiologist and chemist Felix Hoppe-Seyler (1825–1895) to study the chemistry of cell nuclei. He used leucocyte cells that were generally difficult to obtain in adequate numbers for study. However, they were known to make up a significant amount of the pus found in the bandages from healing wounds, thus he obtained his supply from a nearby hospital. Miescher developed a salt solution with sodium sulphate to "wash" the cells off the bandages without damaging the cells in the process. After treating the pus with sodium sulphate, he filtered and centrifuged it, and then allowed the residue to sink to the bottom of a glass beaker. He then attempted to separate the cell nuclei from the cell cytoplasm by further acidifying the precipitate that formed. Miescher called it "nuclein" (which is now known as DNA). Through further research he was the first to identify that this molecule contains phosphorus, nitrogen, and sulfur, as well as other elements, such as carbon, oxygen, and hydrogen. This was an unusual animal cell molecule because it contained the element phosphorus. He and his students contributed extensive research on the chemistry of this unusual molecule that eventually led to the important and later discovery that nucleic acid (DNA) is the carrier of inheritance. One of Miescher's other research discoveries established that the concentration of carbon dioxide in the blood was responsible for regulating breathing.

See also Crick, Franklin (Rosalind); Meselson

MILLER'S THEORY FOR THE ORIGIN OF LIFE: Chemistry: *Stanley Lloyd Miller* (1930–2007), United States.

> *Under conditions of primitive Earth, the correct mixture of chemicals along with the input of energy could spontaneously form amino acids, the building blocks of life.*

As a graduate student of Harold Urey, Stanley Miller conducted experiments at the University of Chicago to demonstrate how life could have started on Earth at an early stage of existence. He theorized that the primitive atmosphere on Earth was the same as now exists on some of the other planets. For example, Jupiter and Saturn are very rich in methane gas (CH_4) and ammonia (NH_3), as well as possibly water and lightning, and these conditions could be responsible for the formation of life. In his laboratory Miller attempted to recreate a primordial environment where an **autocatalytic** process might facilitate the formation of **prebiotic** life to from organic molecules from inorganic elements. Miller combined ammonia, methane, hydrogen, and water vapor and subjected the enclosed mixture to discharges of high-voltage electricity. After a period of time he analyzed the mixture by using paper chromatography and detected several organic substances including hydrocyanic acid, formic acid, acetic acid, lactic acid, as well as urea. In addition, there were two basic amino acids: glycine and alanine. This experiment was conducted many times with various mixtures and sources of energy. A number of scientists saw this as the basis for an explanation of how life began because Miller produced some complex organic molecules. Unfortunately, additional experiments and the further production of some organic molecules came nowhere near forming a substance that could reproduce and maintain its metabolism. The current thinking is that life was formed by a random process, such as are the processes of mutation and evolution, and that it may require the application of some new, possibly unknown, principles to form complex organic life from inorganic substances, or that life arrived on Earth from some source in outer space.

See also Darwin; Margulis; Ponnamperuma; Urey

MILLIKAN'S THEORY FOR THE CHARGE OF ELECTRONS: Physics: *Robert Andres Millikan* (1868–1953), United States.

By indirectly measuring the effects on electrons by an electrical field whose intensity is known, the charge on the electron can be calculated.

Robert Millikan knew of James J. Thomson's 1896 discovery of the electron, as well as Thomson's use of the Wilson cloud chamber to compare the charge of an electron to its mass (e/m) and arrive at an approximate charge for the electron, which he stated as $4.744 \pm 0.009 \times 10^{-10}$ electrostatic units, which was a somewhat inaccurate measurement. Today the constant for the electron charge is stated as $\pm 1 \times 10^{-19}$ Coulombs. Millikan conceived of a device similar to the Wilson cloud chamber that used an electrostatic charge instead of a magnetic field to measure the charge of the electron (*see also* C. Wilson). This was the classical "oil drop" experiment. He atomized tiny oil droplets, which, due to the "friction" of falling, obtained a charge of static electricity as they fell through a small opening between two charged plates. Millikan created a variable electric potential between the plates (+ and − charges) and exposed this area with a light beam enabling him, with the use of a microscope, to observe what occurred as the charged drops fell through the small opening between the charged plates. When the current was off, there was no charge on the plates, thus permitting the oil drops to fall at a constant rate due to gravity. As he adjusted the charges on the plates, the oil drops were deflected up or down according to several factors (the electrical potential between the charged plates, gravity, the electron's mass, and its electrical charge). He calculated the basic charge on an electron, a constant unit in physics, to be 4.774×10^{-10} ($\pm$ 0.009) electrostatic units. With this information and using Thomson's data for the e/m formula, Millikan determined the electron has only about 1/1836th the mass of a hydrogen ion (a proton).

See also Compton; Thomson; Wilson (Charles)

MINKOWSKI'S SPACE-TIME THEORY: Physics: *Hermann Minkowski* (1864–1909), Germany.

Any event occurring in both local space and time exists in the fourth dimension of space-time.

In 1907 Hermann Minkowski proposed his theory known as "Minkowski space." His space-time concept provided the mathematics for local (measurable continuum) events occurring simultaneously that led to Einstein's general theory of relativity published in 1916. In addition to the three dimensions of space (x, y, and z, or width, height, and depth), Minkowski's theory included the fourth dimension of time; thus *space-time* represents the inertial frame of reference for all bodies in motion. This concept indicated that such a phenomenon would account for a curvature of space-time, which accounts for gravity.

See also Einstein

MINSKY'S THEORY OF ARTIFICIAL INTELLIGENCE (AI): Mathematics and Computer Science: *Marvin Lee Minsky* (1927–), United States.

Artificial brains could be "grown" and self-replicated to be intelligent and with the ability to learn as do human brains through the interactions of nonintelligent parts.

Marvin Minsky's theory is based on his work with several other computer theorists related to how artificial brains could be "grown" by a process somewhat similar to the development of human brains. The key seems to be based on understanding how the human brain programs language, behavior, emotions, and so on, and how such human activities are related to the working of the brain's randomly "wired" neural networks. His theory was based on the concept that a computer could be "wired" and programmed to replicate the similar randomly "wired" neural network of the human brain.

Minsky rejects the need for better supercomputers as means to build better artificial intelligence (AI) computers; rather what is needed is a better understanding of what software to use with them. The best computers today are faster than the human brain in processing information, and such computers could act as AI "brains" if we knew what software to develop and use. Today, vast amounts of information are available via computers, but in many ways computers are very limited. Computers cannot answer commonsense human questions based on emotions or even those that are self-evident in the day-to-day interactions among people. Computers have no remorse. Computers associated with robots can perform repetitive mechanical tasks in factories and solve complicated mathematical equations. Although they can read, they can neither understand nor explain a simple story in a book. They can beat the best human chess players, but they cannot run a successful household for the simple reason that running a successful home

Marvin Minsky did most of his work related to artificial intelligence with colleagues at The Artificial Intelligence Laboratory (AI LAB) at the Massachusetts Institute of Technology (MIT) that he and fellow computer scientist John McCarthy (1927–) established in 1959. In 1974 Minsky introduced a new concept for how the human mind can understand a number of different things about a specific topic. He called his theory "frames" for a collection of specific knowledge about a topic stored in the mind. For instance, a "fish" frame would store all kinds of information about fish, thus not requiring the mind to remember and recall each and every aspect about fish already known. He has spent most of his career at MIT working on his theories. In addition to his research in AI, he has contributed to the fields of mathematics, cognitive psychology, linguistics, optics, in particular using computers in robots for mechanical manipulations, vision, and understanding language. His inventions include several robotic devices for hands and limbs, the "Muse" which is a musical synthesizer, and the Confocal Scanning Microscope that is an optical machine that has superb image resolution. He also constructed SNARC (Stochastic Neural-Analog Reinforcement Computer), the first randomly wired neural network learning machine. In 1985 he published an unusual book *The Society of Mind* that was composed of 279 one-page ideas related to his theories. Each page was in some way related to another page and was a solution to a problem related to a specific psychological phenomenon.

requires a wider range of abilities, including the ability to adapt to more types of random chaotic situations than any known chess movements.

MISNER'S THEORY FOR THE ORIGIN OF THE UNIVERSE: Astronomy: *Charles William Misner* (1932–), United States.

> *The universe began in a nonuniform state, which in time became uniform as it expanded due to natural forces and physical laws.*

Charles Misner based his "mixmaster" model for the origin of the universe on the idea known as the *horizon paradox*. He theorized that in the beginning, all forms of matter were very much mixed up, with no or very little order. As the universe expanded, forces such as friction and gravity affected this diverse mixture and formed a more homogenous, isotropic, and uniform universe. His evidence was the horizon paradox, which states that the universe, when viewed from Earth, is so huge that it appears, even to incoming microwave signals, as a very uniform structure—just as when viewing the horizon of Earth, the distant landscape on earth appears more uniform than when viewing the same scene up close (e.g., viewing Earth from airplanes). Misner's mixmaster concept and the horizon paradox provided support for the big bang inflationary theory for the origin of the universe.

See also Gamow; Guth

MITSCHERLICH'S LAW OF ISOMORPHISM: Chemistry: *Eilhard Mitscherlich* (1794–1863), Germany.

> *Substances with identical crystalline forms (isomorphism) also have similar chemical compositions and formulas.*

Early in his academic career, Eilhard Mitscherlich studied oriental languages in Germany but then became interested in medicine while in Göttingen, Germany, in 1817. For reasons unknown, his interests turned to a then-popular area of study in chemistry known as crystallography. He discovered that similar compounds tend to crystallize together. He, therefore, surmised that if compounds crystallize together, they are most likely to have a similar structure. He came up with this concept after he demonstrated that manganates, chromates, sulphates, and selenates are all isomorphous. In other words, the formula of the just-discovered selenates could be deduced from the well-known formulae of the other three (manganates, chromates, and sulphates). This idea was confirmed when the atomic mass of selenium was discovered in the early 1800s. Mitscherlich stated his "law of isomorphism" as: If compounds crystallize together, they are probably of similar structure (have the same formula). During this time he worked in Stockholm with his mentor the famous chemist Jöns Jakob Berzelius who along with Wilhelm Hisinger is credited with the discovery of selenium. Upon his return to Germany in 1822, he was appointed to the head of the department of chemistry. While continuing his research with crystallography, he also studied organic chemistry, microbiology, and geology. He was the first to produce benzene by heating calcium benzoate and furthered the development of the industrial process of extracting cellulose from wood pulp. Mitscherlich's law of isomorphism was very useful to Berzelius and other chemists in identifying the formulas of other elements and determining their atomic mass. The law also aided Dmitri Mendeleev in determining the atomic weights (masses) of elements as a format for arranging individual elements in his **Periodic Table of the Chemical Elements**. Later the elements were arranged by their atomic numbers (number of protons in the elements' nuclei) rather than atomic masses.

MOHOROVICIC'S THEORY OF THE EARTH'S INTERIOR STRUCTURE: Geology: *Andrija Mohorovicic* (1857–1936), Croatia.

There are definite boundaries between Earth's crust and mantle.

Based on his observation of an earthquake that occurred in 1909 in his native Croatia, Andrija Mohorovicic believed there was a boundary between the layers of Earth. Using a seismograph, he recorded waves from an earthquake as they penetrated the deep areas of Earth and compared them with the waves that traveled on the surface. He discovered the waves from a deep layer traveled back to Earth faster than did the surface waves, because the deep mantle layer was of greater density than the crust at the surface (the denser the medium, the greater will be the speed of sound and vibrations traveling through it). He concluded that there must be a relatively abrupt separation between these two layers with the mantle starting about 20 to 25 miles below the surface (crust). It was later determined the crust under the oceans is much thinner—only about three miles deep. The continental surface crust ranges in thickness from 22 miles in valleys to about 38 miles under mountains. The mantle is about 1,800 miles thick, and the outer core is about 1,400 or 1,500 miles thick, with an inner core of about 1,500 miles in diameter. This discontinuity between the crust and mantle was named after Mohorovicic and is sometimes referred to as the "Moho."

> In 1960 the National Science Foundation (NSF) sponsored a project to drill into the Mohorovicic discontinuity. At the time the deepest well drilled on Earth was about 10 km (6.2 miles). Therefore, to reach the Moho, it would be necessary to drill about three times that depth on land. The project was abandoned due to a lack of resources and the realization that the tremendous heat at that depth would destroy most drilling equipment. Temperatures increase about 15° to 75°C (59° to 167°F) for every kilometer drilled into Earth; therefore, at just a bit deeper than 25 km the temperatures would be almost 2,000°C. Iron melts at 1,536°C.

MONTAGNIER'S THEORY FOR THE HIV VIRUS: Medicine: *Luc Montagnier* (1932–), France.

A number of biomolecular mechanisms may be responsible for a depletion of lymphocytes in HIV-infected individuals.

In 1983 in Africa, Luc Montagnier and his colleagues discovered and isolated the human **retrovirus**, named HIV-1, which is related to AIDS. Later his team discovered a second retrovirus, HIV-2 (animal retroviruses were known, but they were not generally associated with humans). Montagnier's theory states that HIV exhibits characteristics of a retrovirus, which is the main mechanism that reduces the bacterial-viral-fighting lymphocytes in the human immune system, thus allowing **AIDS** to develop. He also investigated several other possible mechanisms that could relate the virus to AIDS. In the meantime, Robert Gallo of the United States, using a sample of Montagnier's retroviruses, discovered two viruses, one similar to HIV-1 and HIV-2, which Gallo named HTLV-1, and later another variety named HTLV-3, both of which were found in T-4 cells (special lymphocytes of the immune system). The viruses Gallo identified were not exactly the same as Montagnier's but may have been mutations of HIV. A dispute arose over who discovered what and when, which eventually was settled by naming Montagnier's virus LAV and Gallo's as HTLV-3. In 1986 it was agreed that all varieties of the retrovirus would henceforth be called HIV.

See also Baltimore; Delbruck; Gallo

MOORE'S LAW: Mathematics and Computer Science: *Gordon Earl Moore* (1929–), United States.

Moore's law states: *The number of transistors on integrated circuits will double in complexity every eighteen months.*

This empirical observation was made in 1965 and is attributed to Gordon Earl Moore who cofounded the Intel Corporation in 1968. Moore did not name his statement "Moore's law," but rather his statement was given that name by Carver Mead (1934–), a professor and computer scientist at the California Institute of Technology. By 1970 it was common to consider Moore's law as a reference to how rapid advancements in computing power is related to per unit cost of transistors because complex transistors are also a measure of computer processing power. Moore claims that he originally stated that the cycle of technology of chip improvements would occur every two years instead of every eighteen months. He said he was misquoted. However, it is now and forevermore stated as "every eighteen months."

Moore's law as related to computers and transistors is not the first historical statement that pertains to improvements of computer devices and price per component of unit items resulting in today's greatly reduced price, and ever increasing power, of personal computers for home use. Historically, the picture unfolded as follows:

1. Computers were mechanical devices that were utilized in the 1890 U.S. census.
2. Mechanical type computers evolved into Alan Turing's relay-based machine that cracked the Nazi enigma code in World War II.
3. The introduction of the vacuum tube for use in early computers was used in a CBS radio broadcast that accurately predicted the election of General Dwight Eisenhower as president of the United States in 1952.
4. As newly invented transistors improved, they were used in launching satellites into space in the early 1960s.
5. The subsequent revolution of integrated circuits led to their increasing complexity, thus the advent of integrated circuits that led to Moore's law and personal computers.

Some technical experts believe that Moore's law will break down by the year 2020 due to the development of transistors that are only a few atoms or molecules in size.

Even though Moore's law only makes predictions regarding the computer and related components, many people mistakenly believe it applies to all forms of technology, which it does not. The only reason that the costs per chip are kept low is not necessarily related to Moore's law. The processes related to the design, research and development, manufacturing and equipment, testing, and labor, are all involved in the production costs that are in the *reverse* of Moore's law. Therefore, the more complex the chips become, the more the total production cost. Total costs to develop a new chip are in excess of $1 million. Once the first chip is produced at $1 million plus, the manufacturing companies can then begin to sell many more of the powerful chips at a much lower cost, thus making a profit. Moore's law also seems to not only apply to integrated chips but also to the access speeds of hard drives read only memory (ROM) and the capacity of the computer's random access memory (RAM). Some technologists claim that, under Moore's law, everything can become better and better, and thus it is a violation of Murphy's law, which has many different laws and corollaries about things that may not turn out as expected. An example of this is part of Murphy's Law that states: *Anything that can go wrong will go wrong.*

See also Babbage; Noyce; Shockley; Turing

MOSELEY'S LAW: Physics: *Henry Gwyn Jeffreys Moseley* (1887–1915), England.

> *There is a distinct relationship between the X-ray spectrum and the proton number of chemical elements. When exposed to X-rays, each element with its specific atomic number produces a unique spectrum of wavelengths.*

Henry Moseley, using X-ray spectrometry, examined the lengths of electromagnetic waves emitted by different elements when exposed to X-rays. He observed that each element produced its own specific wavelength, which he examined by using crystal diffraction. His data indicated that, each element might be considered a separate integer that is proportional to the square root of the frequency of its specific wavelength. We now refer to this integer as the *atomic number,* which is the number of positive protons in an atom's nucleus that determines a specific element's physical and chemical properties. Moseley's data improved Mendeleev's **Periodic Table of the Chemical Elements** by arranging the elements in the table according to their atomic numbers rather than their atomic weights. The crystallographer Rosalind Franklin used X-rays to create patterns of molecules to determine the arrangement of atoms in their molecular structure in 1952. She made microphotographic pictures of the DNA molecule that gave Watson and Crick the insight to determine that the DNA was shaped as a double-helix molecule.

See also Franklin (Rosalind); Mendeleev

MULLER'S THEORY OF MUTATION: Biology: *Hermann Joseph Muller* (1890–1967), United States. Hermann Muller was awarded the 1946 Nobel Prize for physiology of medicine.

> *X-rays and other ionizing radiation can induce chemical reactions that produce genetic mutations.*

Familiar with Mendelian heredity and the concept of genes as the carriers of inherited characteristics, Hermann Muller experimented with the fruit fly *drosophila*. His early research indicated that raising the temperatures of the eggs and sperm of fruit flies led to an increase in the rate of mutations. In 1926 he discovered that X-rays would also cause mutations. Some mutations were recessive, but mostly the mutated genes were dominant and thus harmful and passed onto offspring. He concluded that mutation was a chemical reaction and could be caused by exposing the eggs and sperm to a variety of chemicals and forms of ionizing radiation. Muller was concerned with the increased exposure of humans to all types of ionizing radiation (medical X-rays, nuclear radiation, cosmic radiation, ultraviolet, etc.). He believed excessive amounts of exposure to radiation caused genetic mutations—some positive, but mostly negative—that would be passed onto future generations. There is an ongoing debate as to the consequences of excessive mutations in the general population.

See also Lysenko; Mendel

MULLIKEN'S THEORY OF CHEMICAL BONDING: Chemistry: *Robert Sanderson Mulliken* (1896–1986), United States. Robert Mulliken was awarded the 1966 Nobel Prize for Chemistry.

> *Nuclei of atoms produce fields that determine the movement of electrons in their orbits. Thus, the orbits of electrons for atoms combined in molecules may overlap and include two or more molecules.*

Robert Mulliken formulated the concept of molecular orbits in which the valence electrons located in the outer orbits are not bound to any particular atom but may be shared with several different atoms within a molecule. Familiar with Niels Bohr's quantum electron orbital model of the atom, Mulliken and his colleague, the German physicist Friedrich Hund (1896–1997), applied quantum mechanics to explain how the valence electrons are delocalized in the molecular orbit where the bonding (combining) takes place (*see* Figure S2 under Sidgwick). In other words, the orbiting electrons of isolated atoms become molecular orbitals that may represent two or more atoms for each molecule. Thus, the energy of bonds could be determined by the amount of overlap of atomic orbitals within the molecular orbitals. This may be one reason that there are so few "free" atoms of elements in the universe. They are mostly joined in a great variety of molecular compounds. The concept of electronegativity that Mulliken devised is related to chemical bonding. *Electronegativity* is the ability of a specific atom within a molecule to attract electrons to itself and thus enable the molecule to carry an extra negative charge. To explain this phenomenon, he developed the formula $\frac{1}{2}(I + E)$, where I is the ionization potential of the atom and E is the atom's affinity for electrons.

See also Bohr

MULLIS' THEORY FOR ENZYMATIC REPLICATION OF DNA: Biology/Biochemistry: *Kary Banks Mullis* (1944–), United States. Kary Mullis shared the 1993 Nobel Prize for Chemistry with Canadian microbiologist Michael Smith (1932–2000).

Mullis' theory states: *Using a controlled temperature applied to a segment of the DNA molecule will cause the helix to unravel, resulting in fragmentations that then can be reproduced as unlimited copies in vitro.*

The original process for replicating and identifying DNA fragments was slow and cumbersome and required the use of living organisms. It was a time consuming effort. Kary Mullis developed the "polymerase chain reaction," now referred to as PCR. Mullis' PCR method began in vitro, meaning "outside the living organism" and thus could be accomplished more rapidly in a simplified laboratory environment using only heat, reagents, and test tubes.

Dr. Kary Mullis received some notoriety as a potential forensic DNA analyst in the 1995 O.J. Simpson murder trial due to his extensive work in this area. He was scheduled to be an expert defense witness. However, he was not called as it was learned that the prosecution planned to discredit Mullis because of his known eccentric behavior, his many failed marriages, legal patent disputes, use of controlled substances (LSD), and in general his unconventional lifestyle. In the end, the defense presented information that convinced the jury that DNA evidence was not viable or reliable.

Although Kary Mullis conceived of the idea for amplifying fragments of DNA to simplify analysis of base pairs, it was his colleagues at Cetus who, over a period of seven years, reduced his ideas into practical laboratory procedures. Thus, many consider the success of the process to be a team effort. Cetus Corporation patented the PCR techniques in Mullis' name in 1983. This was followed by several lawsuits. Hoffmann-La Roche purchased the patent rights in 1992, but the rights expired in 2006, leaving ownership unsettled after that date. Kary Mullis received many awards for his work in biotechnology, including an award from the German Society of Clinical Chemistry in 1990, the National Biotechnology Award in 1991, the Research and Development Scientists of the Year Award also in 1991, the Scientist of the Year Award in 1992, and the Thomas A. Edison Award in 1993. He was inducted into the National Inventors Hall of Fame in 1998. Dr. Mullis has received other awards, including the Nobel Prize in Chemistry in 1993. He has many publications to his credit. His best known is his ''memoir'' titled *Dancing Naked in the Mind Field.*

After receiving his BS in chemistry from the Georgia Institute of Technology in 1966, he continued his education receiving his PhD in biochemistry from the University of California, Berkeley in 1972. In 1979 he joined the Cetus Corporation, a new biotech firm in Emeryville, California, where he conducted research on synthesis of oligonucleotides (fragments of DNA or RNA containing fewer than fifty nucleotides) and invented the PCR method in 1983. According to Dr. Mullis, as he was driving through the mountains of Mendocino Country, California, he mentally conceived of a new way to analyze changes in DNA by amplifying individual sections or regions of the DNA molecule. He came up with the idea of taking genetic material from a single molecule of DNA and using what he later called his PCR method that could replicated to over one hundred billion related molecules in a few hours. And, the method requires only the application of heat and a few pieces of laboratory equipment. The PCR method is now used for biological and medical research as well as for forensic purposes. It can be used to detect hereditary diseases, to identify DNA genetic fingerprints, the cloning of genes, paternity testing, identifying mutated genes, diagnostic testing, pharmacogenetic tailoring of specific drugs for specific diseases, and so forth. PCR also can be used in a new type of science known as "paleobiology" which is the analysis of ancient DNA from fossil bones. This idea led to the story and movie of *Jurassic Park* where a variety of dinosaurs were recreated from DNA of fossils millions of years old.

N

NAMBU'S THEORY FOR THE "STANDARD MODEL": Physics: *Yoichiro Nambu* (1921–), Japan.

> *Quarks can exist with three values, one of which is an extra quantum number referred to as color.*

The "standard model" is one of several postulates of the quantum theory that is applicable to both submicro (quarks) and macro (supernovae) events. The other two deal with the quanta nature (tiny packets) of energy and the particle-wave nature of matter. Yoichiro Nambu investigated "baryons" which are particles with three quarks exhibiting one-half spin as they interact with the strong force. The regular proton in the nucleus has only two "up" quarks and one "down" quark, with the symbol *uud* used to designate this structure. Baryons comprise three identical quarks referred to as "strange" quarks, with the symbol *sss* designating their structure. Nambu's theory stated that quarks really exhibited a value of 3, with an extra quantum number referred to as "color." The terms "up," "down," "strange," and "color" are arbitrary and do not mean the same as the words are commonly used but refer to the particles' orientations in space and spin directions. The three arbitrary colors are red, green, and blue, which enabled quantum rules to be followed by allowing three up quarks (uuu), three down quarks (ddd) or three strange quarks (sss) to exist as long as each "triple" quark has one of the three different "colors." This is now known as the **Standard Model** for elementary particles (quarks) obeying the dictates of quantum theory. Nambu's theory was expanded to explain the possibility for the absence of free quarks, which, if detected, would exist as massless, one-dimensional entities. He suggested that the reason "free" quarks have yet to be detected is that they are located at the ends of "strings." Thus, this became known as the *string theory*, which had some problems when a string was "cut," which produced a quark and an antiquark pair but not a "free" quark. The string theory was later revised and is now known as the *superstring theory*. The string theory itself has generated much debate because so far it is only a mathematical possibility that has not made any viable predictions, which is required to be classified as a "true" theory.

See also De Broglie; Gell-Mann; Hawking; Schrödinger

NASH'S EMBEDDING THEOREMS: Mathematics: *John F. Nash, Jr.* (1928–), United States. John Nash shared the 1994 Sveriges Riksbank in Economic Science that is also known as the Nobel Prize in Economics with German economist Reinhard Selten (1930–) and John Harsanyi (1920–2000) from the United States.

The Nash embedding theorems state: *Every Riemannian manifold can be isometrically embedded in a Euclidean space of R^n.*

"Isometrically" refers to a mathematical means of preserving the lengths of curves that can result in a way to visualize a submanifold of Euclidean space. The complete explanation of Nash's theorems is extremely technical and beyond the scope of this book. The first theorem for the smooth embedding, known as C^1, was published in 1954, and the second theorem, known as C^k, was published in 1956. John Nash accomplished the analysis related to these two theorems in 1966.

John Nash had a very unusual childhood, and his adulthood has been troubled and challenging. He did not enjoy working with other people and even at a young age preferred to do things alone and in his own way. At twelve years of age he had a laboratory in his room at home in West Virginia, and while in high school attended classes in a nearby college. He received a Westinghouse scholarship to attend Carnegie Mellon University in Pittsburgh, Pennsylvania, where he began taking courses in engineering, but soon changed to chemistry and later mathematics. After graduation he worked on a Navy research project in Maryland. He then enrolled in Princeton University, Princeton, New Jersey, where he earned a PhD in 1950. Nash was interested in equilibrium theory as related to N-person Games (N = any number), and later in two-person games as competitive economics theory. He married a physics student from El Salvador named Alicia de Lardé in 1957. Shortly thereafter, he began to exhibit the symptoms of schizophrenia. In 1959 Alice Nash had him committed to a mental hospital where the diagnosis of schizophrenia was confirmed. Their son, John Charles Martin, was born while he was a patient, but Alicia did not give the child a name for a year because she thought John Nash should participate in naming their son. Their son, who is also a mathematician, was diagnosed with schizophrenia just as his father. John Nash has another son from a previous relationship, but contact between the two has been sporadic and difficult. John and Alicia were divorced in 1963 but moved into the same house in 1970 and lived independent lives. Alicia claimed he was just an unrelated boarder. At Princeton he became known as "The Phantom of Fine Hall" (the mathematics center), and during the middle of the night he would often sneak into classrooms where he wrote odd equations on blackboards.

John Nash is widely known, primarily because of Sylvia Nasar's 1998 biography of his life titled *A Beautiful Mind,* which was later made into an Academy Award–winning movie. However, the movie bore little resemblance to Nash's real life. John Nash's more recent work at Princeton involves advanced game theories. He still prefers to work on problems of his own selections. In the fields of pure mathematics and economics, he is best known for his *embedding theorem* that describes the abstract Reimannian manifold that can be isometrically shown as a submanifold of Euclidean space.

NATHANS' THEORY FOR RESTRICTION ENZYMES: Microbiology: *Daniel Nathans* (1928–1999), United States. Daniel Nathans shared the 1978 Nobel Prize for Physiology or Medicine with two other microbiologists, Hamilton Smith and Werner Arber from Switzerland for the discovery of restriction enzymes.

Restriction enzymes are mechanisms evolved by bacteria to resist viral attack and restrict infections caused by particular bacteriophages by removal of viral sequences.

A restriction enzyme cuts the double-stranded helix of DNA by making two slices through ends of the phosphate backbones of the double helix, but without damaging the base pairs. This provides an opportunity for appropriate procedures of molecular biology and genetic engineering to be used.

Hamilton Smith (1931–), the American microbiologist, was the first to identify the restriction enzyme in 1970. This opened the door for microbiologists as a procedure for mapping genes. This development inspired Daniel Nathans in 1969 to work on the simian virus (SV40) that causes tumors. Nathans was able to demonstrate that the virus could be split into eleven unique fragments. He then determined the order of the fragments that indicated the method of fully mapping genes. In addition, the technique provided information that proved helpful to others pursuing research in DNA recombination.

In addition to sharing the Nobel Prize, Daniel Nathans was awarded the National Medal of Science in 1993 and served as president of Johns Hopkins University in Baltimore, Maryland from 1995 to 1996.

See also Arber

NATTA'S THEORY FOR HIGH POLYMERS: Chemistry: *Giulio Natta* (1903–1979), Italy. Giulio Natta shared the 1963 Nobel Prize in Chemistry with the German chemist Karl Ziegler (1898–1973) for their work on high polymers.

Adding the proper catalysts during the process of polymerizing straight-chain polymers will produce superior and stronger forms of high polymers.

A polymer is a chemical compound with a molecular weight comprising individual units that are linked to one another by covalent bonds. A polymer's molecules are bonded together to form three different types of polymer structures, as follows: 1) *monomers* that are structures formed by single molecules, 2) *dimers* are two monomers that blend with each other, and 3) *trimers* formed by a combination of three monomers. The latter types of polymers are generally classified as *high polymers* of which there are two types: 1) *linear* high polymers having two bonding sites comprised of units and formed in a chain arrangement and 2) *nonlinear* high polymers having units, each arranged with three bonding sites. High polymers have a wide application due to their unique properties that include high melting points, resistance to moisture, and other chemicals. They provide a high degree of stability, making them ideal for application when heat is used, such as in sterilization equipment for the medical and dental professions. Some specific examples of the use of high polymers in everyday life are well-known plastics, such as ethylene and styrene, and useful products such as ethylene glycol (antifreeze), glycerin, and divinyl benzene.

The *addition* types of polymers have a repeating molecular unit (similar to the monomers), which are used to produce polyethylene and polystyrene, while *condensation* type polymers have units consisting of fewer atoms that repeat what is contained in a monomer. Examples of the products resulting from condensation polymerization are polyesters and polycarbonates. Natta applied various catalysts to propene (a hydrocarbon chain molecule) to form polypropene, a plastic with superior properties. He also worked on what he called "stereospecific" polymers that had properties of heat resistance and improved strength. Although he was a well-respected chemist, he was criticized for accepting a position at the Milan University in 1938 that opened up as a result of the fascist Italian government's anti-Jewish laws. His colleague, who was Jewish, was forced to resign, and Natta agreed to replace him as head of the Chemical Engineering Department.

NÉEL'S THEORIES OF FERRIMAGNETISM AND ANTIFERROMAGNETISM:

Physics: *Louis Eugène Félix Néel* (1904–2000), France.

> *Ferrimagnetism is an example of a molecular-field theory for the magnetic ordering in a system containing nonequivalent structures of magnetic ions that act as tiny magnets within the system.*

In 1936 Néel did research on magnetic solids that involved a particular magnetic ordering of the solids' particles that he called "antiferromagnetism." This was just the opposite of "ferrimagnetism" where unpaired electrons spins are arranged differently. In a ferrimagnetic material the magnetic moment of the ions (and atoms) on different areas are unequal as well as opposed, resulting in the material being magnetized (also referred to as spontaneous magnetism). For instance, iron contains the Fe^{2+} (ferrous) ion and the Fe^{3+} (ferric) ion and is an example of common magnetic substances. In the 1930s Néel suggested that a new form of magnetism may exist and may act differently than a regular magnet. He called this "antiferromagnetism," an example of which is the compound manganese oxide (MnO) in which the magnetic moments of Mn^{2+} and O^{2-} ions are equal and parallel but oriented in opposite directions (this is the opposite of ferrimagnetism where the magnetic moments of the ions are unequal).

Heating above certain temperatures can disrupt spontaneous coupling of atomic magnets. This temperature, that is different for each type of antiferromagnetic material, is now referred to as the "Néel temperature." Some antiferromagnetic solids have a Néel temperature near room temperature. For others, the temperature may be much higher or even lower. When antiferromagnetic materials are subject to very low temperatures, they exhibit no response when placed in an external magnetic field because the antiparallel structure of the atomic magnets is not altered. However, at high temperatures far above the Néel temperature, some of the atoms break free of their ordered arrangement and become aligned with the magnetic filed. As the temperature increases, the heat agitation increases (kinetic molecular motion), thus preventing atoms from aligning with the magnetic field. Consequently, the magnetism decreases as the temperature increases.

Néel's contributions to solid-state physics and, in particular, his research with the magnetic properties of various solids have been invaluable in the development and improvement of memory components of modern computers. He also contributed to geology by explaining the weak magnetism of certain rocks, thus aiding in the study of Earth's structure and Earth's natural magnetic field.

NEHER'S "PATCH CLAMP" TO RECORD SMALL IONIC CURRENTS: Biology and Physics: *Erwin Neher* (1944–), Germany. Erwin Neher shared the 1991 Nobel Prize for in Physiology or Medicine with Bert Sakmann (1942–), the German cell physiologist.

> *By altering the ''voltage-clamp'' method that invades the cell, the ''patch clamp'' method can sit on the surface of the cell, and thus it is possible to measure the small ionic currents generated by ions passing though the cell membrane.*

Earlier studies identified minute channels (holes) in the surface of cell membranes through which ions (charged particles) pass through the cell's wall to the inside of the cell. Early attempts to detect the small electric current created by the flow of ions through the cell membranes were somewhat invasive to the cells. In 1976 Neher and Sakmann detected the minute current created by ions as they pass through just one of many ion channels in the membrane of a receptor muscle cell without the associated thermal "noise" that overshadowed the currents (*see* Figure N1).

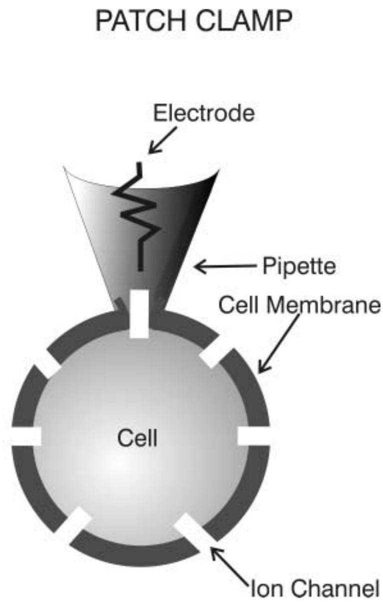

Figure N1. A typical external type of tiny electrode within a very small pipette attached to the outside of a cell to deliver medication through the cell's ion channel.

There are a number of variations of the basic patch clamp technique depending on what aspect of the cell is under study. Some examples are 1) the *cell-attached*

The amazing process of the ''patch clamp'' technique is accomplished by using a tiny pipette that has an opening in its tip of just one micrometer. This pipette has a smooth round electrode tip rather than the sharp microelectrodes formerly used to enter the inside of the cell. This new type pipette-electrode is known as a ''patch clamp electrode'' because it is ''patched'' to the outer surface of the cell. It does not invade the cell itself. The pipette is usually filled with an electrolyte-like solution such as saline solution. Drugs can also be used. A metal electrode at the other end of the pipette is in contact with the fluid in the pipette as well as the ion channel on the surface of the cell. The patch clamp is gently placed onto the cell membrane. Suction is then applied to bring a small amount of the cell's membrane containing an ion channel inside the tip of pipette. This gentle suction creates a seal with the tip of the electrode. As the ions pass though the ion channel in the cell's membrane, the instruments attached to the other end of the electrode record the tiny electric current the ion generates as it passes through the channel in the surface to the inside the cell's membrane. The detection of this small amount of current proved difficult because each channel is the size of the diameter of an ion. Ions are atoms that have gained or lost electrons, and thus, have one or more + or − charges on their surface. Therefore, ions carry a tiny electrical charge and can be affected by tiny electrical currents. As they pass from the end of the micropipette-electrode, they generate a current of only about 10^{-12} amperes. This is an extremely small amount of electricity that proved to be a challenge in the construction of a device that could read these small electrical currents. Thus, the patch clamp system is unique and practical.

patch where the seal is maintained so that drugs can be administered through the ion channel; 2) the *inside-out patch,* where the electrode is withdrawn leaving the patch of membrane attached to the electrode end of the pipette thus exposing the ion channel for study; 3) the *whole-cell patch* increases the suction to break through the membrane and provides access to the inside of the cell as well as improved electrical access to the inside of the cell; 4) the *outside-out patch* is used when the electrode is removed after procedure 3 (above) so that the ion channel can be further investigated; 5) the *perforated patch* is similar to the whole-cell patch (3 above) where a new seal and a new electrolyte solution and an antibiotic fluid in the pipette-electrode are used to significantly shorten the time frame of the experiment. Another variation substitutes the micropipette with a flat patch and is called a *planer patch clamp* which is a small, flat surface material with tiny holes that attaches to the channel cells in the cell's membrane.

NERNST'S HEAT THEOREM: Chemistry: *Walther Hermann Nernst* (1864–1941), Germany. Walther Nernst received the 1920 Nobel Prize for Chemistry.

> *When the temperature approaches absolute zero, so does entropy approach zero (the kinetic energy of atomic motion cease).*

Walther Nernst's heat theorem was based on experimentation with ions in solution and his attempt to determine the specific heat related to chemical reactions. He measured the heat absorbed in a chemical reaction, which fell along with the chemical's temperature as they both (heat and temperature) approached zero kelvin in value (absolute zero −273.16°C). This theorem is called the *third law* and together with the first two laws of thermodynamics is the formulation of the science of thermodynamics. His theorem deals with the calculation of the *absolute* **entropy**, whereas the second law of thermodynamics only measures the *differences* in entropy.

See also Carnot; Clausius; Fourier; Kelvin

NEWCOMB'S THEORY FOR THE SPEED OF LIGHT: Physics: *Simon Newcomb* (1835–1909), United States.

> *The use of statistical methods can improve the accuracy of the constant for the speed of light.*

In 1880, Newcomb, an employee of the U.S. Naval Observatory in Washington, D.C., was ordered by the U.S. secretary of the navy to measure accurately the speed of light. Newcomb applied statistical techniques to data gathered through repeated measurements of the speed of light. He placed a mirror at the base of the Washington Monument in Washington, D.C. He then proceeded to shine a light from his laboratory onto the mirror, measuring the time it took to make a round trip. From these repeated events he recorded his data as a histogram (a graph representing the statistical means of his data in block form), from which he then considered the distribution and confidence interval for the data to arrive at an average figure for the speed of light. He noticed some so-called outliers, which were measurements way off from the average, which he eliminated. Experimental scientists frequently use this technique to exclude spurious measurements that are often artifacts of the measuring instruments and observer errors.

See also Michelson

NEWLANDS' LAW OF OCTAVES: Chemistry: *John Alexander Reina Newlands* (1837–1898), England.

> *The chemical elements, when listed by their atomic weights, show a pattern of certain properties repeating themselves after each group of seven.*

John Newlands first stated his law of octaves in 1864, but it was not accepted as anything more than an odd arrangement of the elements. In essence, his law *states that any given element will have similar characteristics to and behave like another related element when organized in rows of seven according to their increasing atomics weights* (*see* Figure N2). Many scientists used various methods to arrange and classify the fifty-five to sixty then-known elements. The "noble" or inert gases found in Group 8 of the modern **Periodic Table of the Chemical Elements** were not yet discovered. Newlands tried something different. He organized these elements into groups by their atomic weights and noticed that similar elements repeated similar properties when listed by rows of seven. For instance, pairs in the second group of seven (by atomic weight) were similar to the pairs in the first row of seven elements. His elements did not include the unknown Group 8, so this repeating of properties reminded him of the seven intervals of the musical scale, where the same seven notes are repeated several times and the eighth note in each octave (row) resembles the first note in the next higher octave. Therefore, he

NEWLANDS' PERIODIC TABLE

S I M I L A R

I	II	III	IV	V	VI	VII	VIII
H							
Li	Be	B	C	N	O	F	
Na	Mg	Ai	Si	P	S	Cl	
K Cu	Ca Zn	□ □	□ Ti	As V	S Cr	Br Mn	Fe Co Ni
Rb Ag	Rb Ag	In Y	Sn Zr	Sb Nb	Te Mo	□	Rh Rh Pd

P E R I O D S

Figure N2. Newlands organized his Periodic Table according to the concept of octaves in the musical scale where each eighth note in an octave was similar to the first note in the next octave (row).

called his organization of the elements the *law of octaves*, which was later corrected to include the eighth group of the inert noble gases. In addition, Newlands' "table of the elements" did not allow blank spaces for yet-to-be discovered elements, and thus it represented a more realistic organization of the elements than did some other arrangements of the known elements. (Later, the periodic table was improved by organizing the elements by their **atomic numbers** rather than their atomic weights; *see* Figure M5 under Mendeleev for a version of the modern Periodic Table of Chemical Elements.) Following the success of Mendeleev's table, Newlands finally published his law of octaves, which he had withheld due to criticisms of his theory. Since that time, Newlands has been given credit for the original concept of the periodic arrangement of the elements by their atomic weights.

See also: Mendeleev

NEWTON'S LAWS AND PRINCIPLES: Physics: *Sir Isaac Newton* (1642–1727), England.

Newton's first law: *An object at rest will remain at rest, and an object in motion with constant velocity will remain in motion at that velocity unless and until an external force acts on the object.*

This first law refers to the concept of *inertia*, which is the tendency of a body to resist changing its position and/or velocity. Therefore, a body at rest remains at rest, and a moving body will continue to move in its direction with a constant velocity unless acted upon by an external force. This was a major step in revising the ancient concept of motion, which presumed that for a force to move an object, something must be in contact with the object that was "pushing" it. In other words, before Newton's first law, people did not believe in "force at a distance." The accepted belief was that heavenly angels caused the movements of planets or an **aether** in space was pushing them.

Newton's second law: *The sum of all the forces (F) that act on an object is equal to the mass (m) of the object multiplied by the acceleration (a) of the object ($F = ma$).*

Newton's second law explains the relationship between acceleration and force. Acceleration is the rate of change in the velocity of an object with respect to the time involved in the change of velocity. Velocity involves speed of an object and its direction. The second law is expressed as $F = ma$, where F is the force exerted on the mass (m) of the object, and (a) is the acceleration of the object. To determine the acceleration of an object, its mass would be inversely proportionate to the force acting on it: $a = F/m$. Acceleration and force are considered *vectors* (directional arrows) because both have a direction and a magnitude. Vectors can be added and subtracted, so it is possible to arrive at a sum of several forces acting on an object by adding the magnitude of one vector arrow to the next.

Newton's second law also explains the concept of *momentum*, which is the product of an object's mass times its velocity: momentum $= mv$. The rate of change in momentum equals the strength of the force applied to the object. Momentum explains why a heavy automobile going at the same speed as an automobile of lighter weight has more momentum. For example, a twenty-five hundred pound car going at a velocity (speed) of sixty miles per hour has a momentum equal to $2{,}500 \times 60$; while the lighter car weighing just fifteen hundred pounds going at the same speed has a momentum equal to $1{,}500 \times 60$, which is less. However, if they should meet in a head-on accident at sixty mph, the heavier car will sustain less damage than the lighter car because of its greater mass and thus momentum.

Newton's first and second laws of motion led to the concept of *inertial frames of reference*. An inertial frame occurs when an object that has no external forces acting on it continues to move with a constant velocity. This is why, once you start sliding on ice, it is difficult to stop unless there is a force to impede your progress.

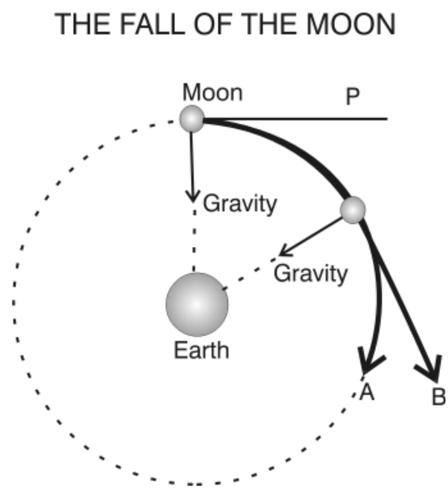

Figure N3. As the moon "falls" toward Earth, due to gravity, its trajectory follows a curved path that misses Earth as the moon follows its trajectory.

Newton's third law of motion: *When two bodies interact, the force exerted on body 1 by body 2 will be equal to (but opposite) the force exerted on body 2 by body 1.*

Another way to say this is, when one object exerts a force on a second object, the second object will exert an equal but opposite force on the first object. It may be expressed as $F_{1*2} = -F_{2*1}$ and is commonly worded as, *for every action, there is an equal and opposite reaction*. This explains why a pot of soup will remain on a table. As the force of weight of the pot of soup "pushes" down, the table is also pushing up on the pot with an equal and opposite force. Sometimes this relationship can be exaggerated. For instance, when a person walks on the ground, he or she is exerting a backward force on Earth while Earth is exerting an equal and opposite force on the person propelling the person forward. Thus, while the person moves forward, Earth does not seem to move backward because it has a much greater mass than a human. However, if the person and the other object (e.g., a ball the same mass as the person) had identical masses, not much progress would be made by walking. Another example is the equal-and-opposite reaction in a rocket motor. Many people believe the exhaust fire and fumes "push" against the air behind the rocket and thus propel the rocket forward. But there is no air in space, and rockets surely operate in space. The greater the mass of the exhaust exiting the rear of the rocket with tremendous velocities, the greater will be the opposite (and equal) reaction inside the front end of the rocket pushing the rocket forward. Therefore, air (or an aether) is not required for a rocket's exhaust to "push" against. Rather, the faster the gases (and the greater the mass of the exhaust) are expelled, the greater is the opposite reaction to the direction of the gases.

It might be mentioned that Newton's first two laws of motion were related to the concept of inertia first generalized by Galileo. The first law is actually a special case of the second law, and both were based on Galileo's observations. Newton's third law was original. It was never conceived by anyone before him. When considered with the second law, the third law describes the concept of mass in terms of a particular mass's inertial properties. In other words, mass cannot be defined except in terms of its inertial and gravitational properties, along with the concept of force.

Newton's law of gravity: *Two bodies of mass (mass$_1$ and mass$_2$), separated by a distance r, will exert an attractive force on each other proportional to the square of the distance separating them.*

Galileo demonstrated that all bodies in free fall do so with an equal acceleration. In other words, he determined that, disregarding air and other sources of friction, two bodies of unequal weights would accelerate at the same rate when in free fall. He came very close to explaining gravity, but it was Newton who applied the mathematics of his three laws of motion (in particular the third law) to the concept of constant gravitational acceleration as applied to all bodies. The force of gravity is expressed as $F = Gm_1m_2/d^2$ where F is the force, G is the proportional constant for gravity, m_1 and m_2 are the masses of the two bodies, and d^2 is the square of the distance between them. Newton determined that the force of gravity is the cause of the acceleration of a body, and the motion of that body does not change the gradational force. In other words, the rate of acceleration is independent of the force and thus is a property of the body, that is, its mass. Weight is distinguished from mass in the sense that the weight of an object (on Earth) is dependent on the attraction between the object and Earth. In real life, Earth is so much more massive than the object that Earth does most of the attracting. Thus, the more massive the object on Earth, the more it weighs. The force of gravity on an object determines weight. Because the moon has less mass than Earth, its gravity is about one-sixth that of Earth. Therefore, a 180-pound person would weigh only thirty pounds on the moon. The mass of an object might be thought of as the amount of "stuff" in the object; it is the same anywhere the object is located in the universe. In 1665 Newton applied his concepts of motion and gravity to describe why the moon orbits Earth. He figured that the moon was constantly "falling" to Earth as the law of gravity was acting on both bodies. Although the moon is far enough away from Earth, as its inertia tends to move the moon at a right angle in relation to Earth, gravity tends to "pull" the two bodies together. Thus, as the moon "fall" towards Earth, its trajectory follows a curved path that misses Earth as it proceeds in its orbit—eternally falling toward Earth, but missing Earth (*see* Figure N3).

This is the same explanation of why our modern Earth-orbiting satellites remain in orbit. They are continually falling toward Earth, but they are high enough and their velocity (and inertia) is adequate to cause them to miss the surface and just keep falling.

Newton's theories of light: *1) Light is composed of a great multitude of very tiny particles of different sizes, which are reflected by shiny polished surfaces. 2) White light is a heterogeneous composition of these different-sized particles, which form rays of different colors.*

Sir Isaac Newton did not accept the wave theory of light, which many other scientists compared with sound waves. His rationale was that light, unlike sound, could not travel around corners. Therefore, light cannot have wave properties and must be composed of a multitude of very tiny particles.

For the second part of his theory, Newton placed a large "plano-convex" lens on a shiny surface and exposed it to direct sunlight. A distinct pattern of rainbow-like concentric rings of colored light became visible near the edges of the lens. Although this was a good indication that light had wave properties, Newton still maintained his corpuscular (tiny particles) theory of light. He also believed white light was composed of light rays of various colors, each color of which was a different-size corpuscular particle. He was determined to prove sunlight was a heterogeneous blend of a variety of light rays (and particles) and that both reflection and refraction could be used to separate these individual-sized particles and rays. To do this, he covered the window of a room to shut out sunlight, leaving a small opening for a narrow shaft of sunlight, which he directed through a prism. Some of the light rays going through the prism were bent (refracted) more than other rays, and together they produced a color spectrum of sunlight (*see* Figure F8 under Fraunhofer). He then placed another prism in contact with the first and discovered that the second prism caused the individual rays to converge back into the white light of the sun. This proved sunlight was indeed composed of different-colored light rays. However, rather than proving his corpuscular theory, it gave further evidence for the wave theory of light, which was further confirmed when new diffusion gratings were used instead of prisms to demonstrate the wave nature of light. Newton delayed publishing his results for several years fearing adverse criticism of his work (*see also* Fraunhofer; Maxwell).

Newton's calculus: *There is a mathematical relationship between the differentiation and integration of small changes for events.*

Newton referred to this as the "fluxional method," which became known as *calculus*. Gottfried Leibniz independently developed what he called differential calculus. Calculus is the branch of mathematics that deals with infinitesimally small changes. It is used extensively in almost all areas of physics, as well as in many other fields of study.

Today, Newton and Leibniz share the honor for the development of calculus.

See also Euler; Galileo; Kepler; Leibniz

NICHOLAS' THEORY OF AN INCOMPLETE UNIVERSE: Astronomy: *Nicholas of Cusa* (1401–1464), Italy.

Because he was a bishop and papal advisor, Nicholas of Cusa's theories assumed a religious and metaphysical leaning. Nevertheless, he proposed some rather revolutionary ideas for his time in history.

His theory states: *There is nothing fixed in the universe, yet it is not infinite.*

Nicholas of Cusa did not accept the theories proposed by Aristotle and other astronomers that the universe was composed of a series of crystal domes over a flat Earth, or the alternative—that the universe was one big sphere with Earth at its center. Nicholas proposed a more flexible universe. It was in a state of becoming where nothing was fixed; there was no outer edge or circumference, and the center was not yet established. Another way to look at this is to consider an infinite circle whose infinite circumference is composed of an infinite straight line. He believed that the universe was extremely complex, with everything in a state of flux and in motion. Even so, God's universe was not infinite. He believed that things are finite, but God is infinite. Some of Nicholas' views including that of the solar system were ahead of his time. He also believed Earth, as well as all the other planets, revolved around the sun.

See also Aristotle; Copernicus; Eudoxus; Galileo

NICOLLE'S THEORY FOR THE CAUSE OF TYPHUS: Biology: *Charles Jules Henri Nicolle* (1866–1936), France. Charles Nicolle received the 1928 Nobel Prize for Physiology or Medicine.

> *The disease typhus is spread by a parasite (body louse) that lives on the patient's body and clothing.*

In the late 1800s Charles Nicolle, director of the Pasteur Institute, was asked to determine the cause of typhus, an infectious disease that had been known to follow wars and plagues as early as 1400 BC. As with measles, people who recovered from typhus were thereafter immune to it. Typhus was also confused with influenza because physicians believed it was spread by "droplet" infection or direct contact with patients'

> The banning of the use of DDT is an example of "good intentions" resulting in "unintended consequences." DDT is an organic insecticide first synthesized by a German chemistry student, Othmar Zeidler (1859–1911) in 1874, although its use as an insecticide was not known until 1939. During World War II DDT was used as an organic insecticide by Allied troops and civilians to control the insects that cause typhus and malaria. Entire cities in Italy were dusted with DDT and the walls in homes were sprayed with it to control mosquitoes. In addition, it was widely used for agricultural purposes. It was considered a rather safe insecticide and was responsible for eradicating typhus in Europe and malaria in Europe and the United States. The progress that improved the health of millions of people came to a halt soon after Rachel Carson published her book, *Silent Spring* in 1962. This book made many controversial claims, among them that DDT causes cancer in humans and destroys wildlife by causing the decline in the population of large birds that is a result of the extremely thin and fragile egg shells preventing reproduction. Her book was a "hit" for many environmentalists because they could now claim that DDT was responsible for many of the health and environmental problems of the world. In years following, many countries banned the use of DDT, even though it is one of the most effective and least harmful of the class of organic insecticides. The results of the ban, mostly in third world countries, are astonishing. It is estimated that over two million people—mostly children—have died each year from malaria since the ban, and that over fifty million people have died because of the ban. It has been proposed that more people have died worldwide from insect borne diseases that could have been controlled by DDT than were killed by Hitler during World War II (Source: Michael Crichton, *State of Fear,* HarperCollins, 2004.) It should be noted that many environmental groups dispute these figures.

clothes or dust. Its death rate was over 50% for adults contracting the disease. Nicolle visited homes where whole families were infected, exposing himself and his coworkers to the infection; several died while gathering information. He observed that though almost all members of a family contracted the disease, once they came to the hospital, it no longer spread. He also noticed a relationship between patients brought to the hospital who were undressed, bathed, and whose clothes were either burned or laundered and the cessation of new infection. As new patients were admitted and went through this procedure, the disease did not spread to others in the hospital. He deduced there must be some type of insect in their clothes or on their bodies.

In 1909 he concluded from this evidence that the culprit was the body louse. Using this knowledge and information, Charles Nicolle experimented with animals, exposing them to the disease carried by the louse. He further established that the typhus germ was not transmitted to a new generation of the louse parasite. Rather, once the germ-carrying adult louse dies, the epidemic ends. He found the guinea pig and some monkeys were susceptible, but not many other animals. Using the blood from infected animals that recovered from the illness, he tried to develop a vaccine to prevent typhus and understand how it affected the immune system. Nicolle's work emphasized the need for better personal and public hygiene to prevent typhus. His discovery that typhus is carried by lice explained why, since ancient times, it is associated with wars. It was not until World War II that the insecticide dichlorodiphenyltrichloroethane (DDT), now banned, was used to control typhus outbreaks in army troops stationed in Italy and other countries, ultimately saving many lives.

NODDACK'S HYPOTHESIS FOR PRODUCING ARTIFICIAL ELEMENTS: Chemistry: *Ida Eva Tacke Noddack* (1896–1979), Germany.

> *When uranium is bombarded with slow neutrons, artificial elements and their isotopes should be produced.*

All isotopes of elements above atomic number 81 are unstable and radioactive. Ida Eva Tacke Noddack was familiar with Enrico Fermi's work with radioactive elements. Fermi realized that fast neutrons that were slowed could more readily penetrate the nuclei of uranium, thus causing fission to occur. This gave Noddack the idea that by bombarding uranium atoms with slow neutrons new isotopes of elements can be produced. This is exactly what occurred when Otto Frisch confirmed Noddack's hypothesis by bombarding the heavy nuclei of uranium with slow neutrons. This bombardment broke up the nuclei into a few large fragments, which proved to be isotopes of other elements (*see also* Fermi; Frisch).

The story of Ida Eva Tacke Noddack's life in science is similar to that of several other women of science who where more or less ignored for their contributions during their time in history. Eva Noddack attended the Technical University in Berlin where she received her PhD in 1921. She joined her future husband Walter Noddack to work on a chemical research project with the German X-ray specialist Otto Berg in 1925. Their collaboration led to the joint discovery of the isolation of element 75 in 1925. It was named *Rhenium* that is Latin for the Rhine River in Germany. In 1926 she married Walter Noddack, and they worked together until his death in 1960. During the span of their marriage they jointly published over one hundred scientific papers. She soon became interested in the work of Enrico Fermi who was the first to bombard uranium with slow neutrons. Fermi believed that he had added neutrons to uranium atoms to produce atoms of elements heavier than uranium, which he called ''transuranic'' elements with atomic numbers higher than uranium 92. Ida Noddack challenged Fermi's claim that he artificially produced new heavier elements by adding neutrons to uranium nuclei. She claimed that he did not make new heavy elements but rather, according to her theory, what he really did was artificially split uranium atoms into isotopes of lighter known elements rather than producing atoms heavier than uranium. In 1934 Ida Noddack suggested her hypothesis that by using Fermi's method of shooting slow neutrons into the nuclei of heavy elements, the results would be fragments of those heavy nuclei and therefore would be isotopes of known lighter elements, and not just other heavier closely related elements. She sent the results of her work on the artificial production of isotopes of heavy elements to Fermi, which he pretty much ignored, as he did with most of the science community. Ida Noddack received a number of awards and was nominated several times for the Nobel Prize in Chemistry but never received it. It has been stated that if Germany during the mid- to late thirties would not have ignored her research, Nazi Germany might have easily won World War II by developing the nuclear (atomic) bomb. The same also applies to the work of Lise Meitner in atomic fission that was also ignored by the patriarchal scientific community in Germany during the 1930s.

NOETHER'S THEOREM: Mathematics: *Amalie Emmy Noether* (1882–1935), Germany.

> *For every differential symmetry generated by local actions, there is a corresponding conserved charge.*

Note: The word "charge" in the above statement is referred to as the "Noether current" that is defined as a nondiverging (nonchanging) vector field.

Symmetry is a basic concept of physical laws and was defined by the German mathematician Hermann Weyl (1885–1955) as: "*That a thing is symmetrical if there is something that you can do to it so that after you have finished doing it, it looks the same as it did before.*" In everyday life there are several types of symmetry. *Bilateral* symmetry is how we are built—each side of our bodies is more or less a mirror image of the other. Also, no matter in what

Amalie Emmy Noether was born in Erlangen, Bavaria, Germany, into a family where her father was a notable mathematician. She showed an early interest in dancing and music at a time when women were not permitted to enter schools in Erlangen. When the local school reversed this restriction in 1904, she enrolled and became known for her publications. In 1915 she moved to the University of Göttingen where she was not allowed to teach. However, she persisted and was finally accepted and even honored until the Nazi racial laws no longer allowed her to teach undergraduate classes in mathematics. In 1935 she fled Germany to Bryn Mawr, Pennsylvania, after she supposedly had an operation in Germany and the doctor reported that she had died during the procedure. She spent the rest of her life at Bryn Mawr and was buried there. Albert Einstein said at her eulogy that she was the most significant creative mathematical genius thus far produced since the higher education of women started.

perspective you look at a cube, it will look the same in all positions. In other words, the symmetry of rotation gives us the law of conservation of linear momentum. *Radial* symmetry is best described by a cylinder that is viewed from the ends, or something going around a central pivot, such as a wheel.

Symmetry is an important concept in physics (*see* the introduction of this book). A major property of symmetry as a physical law is that it is universal. In other words, the laws of physics do not vary with locations in space. When referring to physical laws, no matter what you do to the law, it makes no difference and everything is unchanged. Some examples of the application of Noether's theorem follow:

1. As far as we know, *time* (past, present, and future) does not make a difference in the symmetry of an object in the universe. This invariance gives us the *law of conservation of energy*.
2. When there is no variation with an object's orientation or location in space, the *law of conservation of linear momentum applies*.
3. When the orientation of an object in space does not change with respect to *time*, the result is the *law of conservation of energy*.

NORRISH'S THEORY OF VERY FAST REACTIONS: Chemistry: *Ronald George Wreyford Norrish* (1897–1978), England. Ronald Norrish shared the 1967 Nobel Prize for Chemistry with Norrish's student, the British chemist George Porter (1920–2002), and Manfred Eigen.

An intense burst of light can be used to cause very fast chemical reactions and thus measure and describe intermediate stages of these organic photochemical reactions.

Norrish's theory describes two types of fast reactions, *type I* and *type II*, that involve a cleavage of organic molecules by a flash of light that results in the rapid production of free radicals.

Type I Norrish reactions are photochemical cleavage of aldehydes and ketones into two free radicals (small groups of molecules with a small charge). This occurs when the carbonyl group is excited and accepts a photon that is incorporated into the molecule causing a photochemical reaction to occur. Although of limited utility, Type I Norrish reactions are important for understanding and controlling certain types of organic chemical synthesis.

Type II Norrish reactions are photochemical reactions where a flash of light causes intramolecular changes in the carbonyl group by exciting the carbonyl compound to produce a photon radical.

Norrish's development of these types of light-sensitive organic chemical reactions allowed scientists to study the minute intermediate stages of the reactions and thus improve methods of understanding the procedures involved in the reactions.

See also Eigen

G. W. Norrish was born in Cambridge, England. He finished the Perse Grammar School there and later received a scholarship to study natural science at Emmanuel College in Cambridge University. World War I interrupted his education as he joined the Royal Field Artillery and subsequently in 1918 became a German prisoner of war. After his release from prison camp, Norrish returned to Cambridge and finished his undergraduate degree in 1921. In the late 1930s he was named professor of physical chemistry and director of the department that he maintained until his retirement in 1965. After retirement many of his former students and colleagues in England and abroad joined together to publish a book in his honor titled *Photochemistry and Reaction Kinetics.*

NORTHROP'S HYPOTHESIS FOR THE PROTEIN NATURE OF ENZYMES: Chemistry: *John Howard Northrop* (1891–1987), United States. John Northrop shared the 1946 Nobel Prize for Chemistry with James Sumner and Wendell Stanley (1904–1971).

If enzymes can be crystallized, their composition must be of a protein nature.

Several other chemists claimed that enzymes did not have the characteristics of proteins. In the late 1920s the American chemist James Sumner (1887–1955) claimed to have crystallized the common enzyme *urease*, which manifested the characteristics of a protein. In the early 1930s John Northrop and his colleagues were successful in crystallizing several more important enzymes, including trypsin, pepsin, chymotrypsin, and more important, ribonuclease and deoxyribonuclease (related to RNA and DNA). The exact nature of proteins was difficult to determine because of their very long molecular structures. The crystallization provided a means for identifying the structures of the enzyme and confirmed the theory that they were of a protein nature, enabling scientists to study and understand their chemical composition. Later, Northrop proved that bacteria-type viruses (bacteriophages) also consist of proteins and cause diseases by infecting specific species of bacteria. (See Figure D7 under Delbruck for an artist's version of a bacteriophage.)

NOYCE'S CONCEPT FOR THE INTEGRATED CIRCUIT: Physics: *Robert Norton Noyce* (1927–1989), United States.

A series of transistors can be combined on a small single piece of semiconducting material by etching microscopic transistors onto the surface of a chip to form circuits that can integrate the individual transistors.

Rectifying crystals were in use before the vacuum radio tube was used to control the unidirectional flow of alternating current. They were not very effective, but the concept of using crystals to control the flow of electricity and electromagnetic radiation was not lost on a number of scientists. In the late 1940s, William Shockley, Walter Brattain, and John Bardeen, who were colleagues at Bell Laboratories in New Jersey, used a different substance, a germanium crystal. It was an ineffective conductor of electricity but a good insulator, making it what is now known as a *semiconductor*. Silicon crystals were less expensive and soon replaced germanium as a semiconducting material. It was discovered that if tiny amounts of certain impurities were placed in the semiconductor material, its characteristics could be controlled. These were referred to as solid-state devices, which act as vacuum tubes without having the tubes' large size, generation of heat, or possibility of breakage, and they used very little electricity. Shockley developed this unique device, while the American engineer John Robinson Pierce (1910–2002) gave it the name *transistor*, for its property of transmitting current over a specified resistance (*see* Figure S1 under Shockley). Robert Noyce is credited with the concept of combining a series of transistors onto a small silicon semiconductor chip (about one-fourth square inch or less) to form an integrated circuit. In 1959 Noyce received funding from the Fairchild Corporation to form Fairchild Semiconductor, the first major semiconductor electronics plant in the Silicon Valley of California to exploit the use of the new chip. Later, he formed the INTEL Corporation. In 1959 Noyce filed for a patent for the new chip, even though a few months previously, Jack S. Kilby (1923–2005) of Texas Instruments also filed for a similar patent. After a decade of legal battles, Noyce and Kilby agreed to cross-license their technologies. Kilby later won the Nobel Prize for Physics in 2000 for his part in the invention of the integrated circuit.

See also Shockley

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OCHOA'S THEORY FOR THE SYNTHESIS OF RNA: Biology: *Severo Ochoa de Albornoz* (1905–1993), Spain and United States. Severo Ochoa was awarded the 1959 Nobel Prize for Physiology or Medicine for synthesizing the RNA molecule. He shared the prize with the American biochemist Arthur Kornberg (1918–2007) who synthesized the DNA molecule.

> *The enzyme from a type of bacteria found in sewage can act as catalyst to artificially synthesize ribonucleoside diphosphates into the ribonucleic acid (RNA) molecule.*

Ochoa was the first to determine that high-energy phosphates, such as adenosine triphosphate, are responsible for storing and then releasing energy in human cells. While studying the oxidation process that released energy in cells, he also discovered in 1955 the enzyme located in a particular bacteria that could influence the process of synthesizing the RNA molecule. RNA is of importance in the synthesis of proteins in cells. His work also led him to isolate other enzymes that were related to the citric acid oxidation reactions of the Krebs cycle.

Severo was born in a small town in northern Spain and was named after his father who was a lawyer. At age seven the family moved from their mountain home to the town of Málaga where he was educated in a private school in preparation for college. He started pursuing a career in engineering but found the courses too difficult and soon changed to biology. He received his BA from Málaga College in 1921 and two years later entered the University of Madrid's Medical School. He soon realized that his interests and desires were to do biological research. He received a degree in medicine in 1929 and accepted a postdoctoral appointment at the Kaiser-Wihelm Institute in Berlin. In 1931 after he married Carmen Garcia Cobian, they moved to England to continue his studies and research at London's National Institute for Medical Research.

After a few years he returned to Madrid where his research was partially supported by wealthy patrons. During World War II he and his wife, who became his research assistant, moved to Washington University School of Medicine in St. Louis, Missouri, in the United States. He and his wife conducted much of their research at the University's Cori laboratory, known for its outstanding work with enzymes, metabolism, and biochemical reactions that produce energy in cells. Ochoa added to the work of the Krebs cycle as proposed by Hans Krebs that determined which, and how, food is metabolized to provide energy for the body (*see* Krebs). A gel formed when Ochoa added the enzyme from a type of sewage bacteria to nucleotides. He determined that the gel in the petri dish was a synthetic form of RNA.

Many years later it was determined that Ochoa had isolated the enzyme polynucleotide phosphorylase, which actually *catalyzes* the breakdown of RNA rather than, as he originally believed, *synthesizing* RNA.

See also Krebs

ODLING'S VALENCE THEORY: Chemistry: *William Odling* (1829–1921), England.

Elements can be grouped according to their analogous properties based on their representative values of replacement.

The concept of valence, proposed by Edward Frankland in 1854, was unknown to William Odling. Prior to Frankland's valence concept, Odling proposed that during chemical reactions a distinct ratio existed when one element replaced other elements in a chemical reaction. This was a forerunner of the theory of atomic valences, which is the ability of elements to combine with other elements. It can be expressed as the number of univalent atoms with which they are capable of uniting (*see* Figure S2 under Sidgwick). Some elements may be univalent (1); others are divalent (2), trivalent (3), or tetravalent (4) with respect to the number of univalent atoms with which they can combine. Still other elements may possess variable valences (e.g., nitrogen and phosphorus). At first Odling, as well as other scientists of his time, rejected the existence of atoms. At one time it was incorrectly assumed that just one atom of hydrogen combined with one of oxygen to form water. However, after conducting experiments with oxygen, Odling came to believe in the valence theory. He was the first to realize that oxygen had an atomic weight of 16, not 8. This convinced him that oxygen gas had to be diatomic—a molecule composed of two oxygen atoms. He also speculated about a triatomic molecular form of oxygen (ozone, O_3).

See also Frankland; Sidgwick

OERSTED'S THEORY OF ELECTROMAGNETISM: Physics: *Hans Christian Oersted* (1777–1851), Denmark.

A magnetized compass needle will move at right angles to the direction of an electric current flowing through a wire suspended over the compass.

Hans Christian Oersted's discovery of the relationship between electricity and magnetism (electromagnetism) was accidental. Aware of the experiments dealing with static electricity and the new form of "flowing" electricity described by Alessandro Volta, Oersted performed various "galvanic" experiments using Volta's cells to produce current electricity. He knew of others who demonstrated that by passing an electric current through water, it could be separated into oxygen and hydrogen gases. He believed that this established the connection between electrical forces and chemical reactions and that water must be a compound, not an element, as had been believed for centuries. Oersted then conducted experiments with this new electricity. He attempted to demonstrate that when a wire was heated by carrying electricity, it would act as a magnet and attract a compass needle. He noticed at once that the needle was not attracted to the wire but rather moved ninety degrees from the direction in which the current was flowing in the wire. Saying nothing about this observation to his students, he continued to turn the current in the wire on and off. Each time he did so, the needle of the compass moved at a right angle to the wire. In 1820 he published his results describing the existence of a circular magnetic field between current electricity and magnetism, now known as *electromagnetism*. The unit for the strength of a magnetic field is named after Oersted and is defined as the intensity of a magnetic field's strength expressed in the centimeter-gram-second (cgs) electromagnetic system of physical units. Oersted's concepts sparked many experiments and theories related to electromagnetism, the end result being our modern "electric" oriented society.

See also Ampère; Faraday; Henry; Maxwell; Volta

> Hans Christian Oersted's PhD degree that he received in 1799 was in the field of philosophy, which was not a field of science as we think of science today. To improve his knowledge of science, he traveled throughout Europe to learn about electricity from various physicists. Upon his return to Denmark he began lecturing and giving demonstrations on electricity to the general public. He was so successful that Copenhagen University gave him a professorship in 1806. Although he believed in the concept of electromagnetism, the idea was unproven. It was during one of these lectures when he noticed a needle was deflected when it was brought close to a wire carrying a current. A compass needle was deflected at a ninety-degree angle when the current was flowing but not when the current was turned off. Oersted was also the first person to determine that a circular magnetic field was formed around the wire when a current was flowing through it. Up to this time most of the scientific world had believed that electricity and magnetism were two completely different phenomena.

OHM'S LAW: Physics: *Georg Simon Ohm* (1787–1854), Germany.

A unit of electrical resistance is equal to that of a conductor in which a current of 1 ampere is produced by a potential of 1 volt.

Georg Ohm related electrical resistance to Joseph Fourier's concept of heat resistance, which states the flow of heat between two points of a conductor depends on two factors: 1) the temperature difference between the origin of the point of heat and the end point of the conductor and 2) the physical nature of the conducting material being heated. Ohm speculated how this information related to electricity, and this led to his experimentation with wires of different thicknesses (cross sections). He demonstrated that electrical resistance to current passing through these different wires was directly proportional to the cross section of the wires and inversely proportional to the length of the wires. Almost all effective conductors of heat are also excellent conductors of electricity. The law can be applied to direct and alternating currents. Ohm's law is very versatile and can be used to measure conductance, current density, voltage, **resistors, inductors**, capacitors, and **impedance**. It is stated as R = V/A, where *R* is the natural resistance of the wire (conductor) to the flow of electricity, *V* is voltage, or strength of the electric current divided by *A* which are the amperes, indicating the amount of the electricity (A also may be expressed as I). There is an expression for conductance (G), which is referred to as the reverse ohm (mho), I = GV, where *I* is the amount of current (same as amps), G is the conductance factor of the wire (how well it conducts electricity), and *V* is the voltage. The symbol **Ω** represents electrical resistance and is named after Ohm and is the symbol that indicates the amount of resistance to voltage of one ampere of current. Other physicists did not recognize the importance of Ohm's law for some time, but by the early 1840s, the Royal Society in England accepted his law and Ohm as a member.

See also Ampère; Faraday; Fourier; Volta

OKEN'S CELL THEORY: Biology: *Lorenz Oken* (1779–1851), Germany.

> *Living organisms were not created but rather originated from vesicles (cells) that are the basic units of life.*

In 1805 Lorenz Oken theorized that humans and animals not only originated from but were also composed of cells that he called *vesicles*. Until this point, the source of life—its origin and composition—had been the subject of speculation by scientists, philosophers, and theologians over many centuries. Some believed life began with a "primeval soup" or was carried to Earth from outer space, or was derived from self-organizing inorganic molecules that self-replicated to form organic molecular living cells and tissues, or, more acceptable to many people, but less accurate biologically, life was created by a supreme being. The discovery of fossils and the use of a microscope led to further concepts of living tissue. Robert Hooke viewed tiny enclosures in cork bounded by walls that reminded him of the rooms occupied by monks in monasteries; thus, he named them *cellulae*, meaning "small rooms" in Latin. Oken further speculated that these "cells" were the basic units of life, from which all complex organisms were derived and developed, and he theorized that cellular structure was basic for all organic substances. Oken was one of the first of many scientists to contribute to and expand the concept we now know as the cell theory.

See also Margulis; Schleiden; Schwann; Virchow

OLBERS' PARADOX: Astronomy: *Heinrich Olbers* (1758–1840), Germany.

> *If the universe is old, eternal, unchanging, infinite, and uniformly filled with stars, why is the night sky dark instead of bright?*

Heinrich Olbers' paradox has intrigued astronomers, physicists, and mathematicians for decades. It is based on several questions that are still being investigated by scientists: Is the universe finite or infinite? Is it an evolving and expanding universe or a steady-state universe? Are galaxies (groups of stars) evenly distributed in the heavens, or is space nonhomologous? We know that light follows the basic inverse square law. An appreciation of the inverse square law as related to light can be demonstrated at night by shining a flashlight at a one-foot-square white sheet of cardboard held away from the light at several different distances. The illumination on the cardboard is greater at 10 feet than at 25 feet and greater in intensity at 25 feet than at 100 feet. It will be obvious that the light intensity diminishes as the distance between the flashlight and white cardboard increases (the intensity of the light at different distances can be measured with a light meter). Light, over distance, is dispersed and becomes less focused, but it will travel in a straight line forever if not absorbed or distorted (affected) by gravity in space. Therefore, the intensity of light received on Earth from stars is much reduced from its brightness at the source. But at the same time, the average number of stars, at any given distance, increases in number by the square of the distance to Earth. This is the basic distribution of stars in the universe. Therefore, according to one part of the paradox, the night sky should be as bright as the sun. On the other hand, Olbers claimed that the reason the night sky is not as bright as the sun is that interstellar "dust" absorbs the starlight. Today, this is an unacceptable solution to his paradox because the universe is assumed to have come into existence at a finite time, even though it might be infinite in space. It has a beginning, it has history, it seems to continue to expand, and for the most distant and possibly oldest galaxies, light has not had time to get to Earth. Light does disperse over long distances, and galaxies and their stars are not evenly distributed throughout space. Currently, astronomers using the Hubble Space Telescope and the Gemini North telescope installed at Mauna Kea, Hawaii, are examining the question concerning the universe being finite or infinite. The mirror for the Gemini telescope is 8.1 meters in diameter and only 20 centimeters thick. It is difficult to cast a single piece of glass this size without imperfections or cracking. The mirror is the largest single-piece glass mirror ever cast for a reflector telescope (*see* Figure H3 under Hale). It is expected that both of these instruments will locate galaxies at the limit of the speed of light, which means these distant galaxies are receding faster than the speed of light, which may be considered a boundary formed by the limits of just how far we can see into the past using electromagnetic radiation (light, radio, microwaves, X-rays, etc.) originating from the edge of the universe. Or it might mean that we may never be able to "see" the edge of the universe, even if it is finite. Or, if the universe is forever expanding, it may be too young for light to have reached us. Therefore, Olbers' paradox addresses several phenomena of physics and is a puzzle of unknowns.

OLIPHANT'S CONCEPTS OF ISOTOPES FOR LIGHT ELEMENTS: Physics: *Marcus Laurence Elwin Oliphant* (1901-2000), Australia.

By "shooting" an ion beam at targets of lithium, beryllium, and related elements, new atoms of hydrogen and helium can be created by a process of atomic transformation.

Marcus Oliphant, known as Sir Mark Oliphant, was influenced by Ernest Rutherford's work with the nuclei of atoms. In 1932, Sir James Chadwick bombarded nuclei

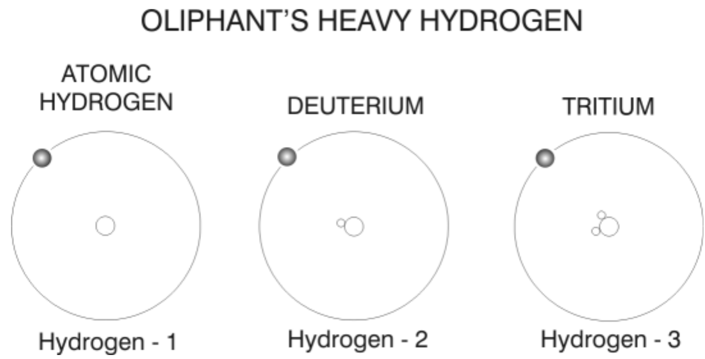

Figure O1. Harold Urey produced heavy hydrogen atoms with one proton and one neutron (deuterons). Marcus Oliphant bombarded deuterons with other deuterons to produce a third isotope of hydrogen—tritium, with two neutrons and one proton. The three isotopes of the hydrogen atom exhibit minor differences in chemical properties due to differences in atomic weights. These differences are minor for chemical reactions involving isotopes of heavier elements. Heavy hydrogen atoms are used to facilitate nuclear reactions.

of atoms and discovered a third basic particle in the atom, the neutron. (The basic particles of atoms are electrons, protons, and neutrons. However, today dozens of subnuclear particles smaller than the proton and neutron have been identified.) Also in 1932, Harold Urey discovered a heavy form of hydrogen called *deuterium*. It was known for some time that the hydrogen atom contained only one particle in its nucleus, the positively charged proton, that made it the lightest of all elements. Urey discovered that the nucleus of hydrogen could also contain a neutron; thus this isotope of hydrogen had an atomic weight of 2 instead of 1, as for ordinary hydrogen. The nuclei of this isotope were referred to as *deuterons*. Oliphant and a colleague bombarded these heavy hydrogen deuterons with other deuterons, producing a new isotope of hydrogen that contained two neutrons plus the proton. Thus, now there were three forms of hydrogen, as follows, H-1, H-2, and H-3 (*see* Figure O1). This third form, composed of one proton and two neutrons, is named *tritium*. It is unstable due to its radioactive nature, with a half-life of about twelve years.

At about the same time, it was discovered that the nuclei of these forms of hydrogen could react with each other, producing other new elements (particularly helium) and releasing tremendous energy. This was the beginning of our understanding of the thermonuclear reactions that take place in the sun, as well as the development of the hydrogen (thermonuclear) bomb. Oliphant moved to the United States and perfected the electromagnetic method for separating rare fissionable uranium (U-235) from the more common form of uranium (U-238). U-235 was used to produce one of the first atomic bombs (the other of the first bombs used plutonium). Oliphant was also the first to realize that nuclear reactors that are used to generate electricity can also produce plutonium. Thus, any country with such a reactor could develop atomic (nuclear) weapons. He became a firm critic of nuclear weapons and an advocate for the peaceful uses of atomic energy.

See also Chadwick; Rutherford; Urey

OORT'S GALAXY AND COMET CLOUD THEORIES: Astronomy: *Jan Hendrik Oort* (1900–1992), Netherlands.

Oort's theory for the structure and motion of the Milky Way: *Composed of billions of stars, our Milky Way rotates as an entire disk, but the rotation is differential, not uniform, because the outer stars rotate at a slower speed than do the inner stars.*

Jan Oort determined several facts about galaxies, including our Milky Way galaxy. He theorized that the rotating stars in a disk galaxy follow Newton's laws of motion, in particular, the concepts of conservation of energy and angular momentum. Therefore, the outer stars move more slowly than do the inner ones (according to angular momentum) in the gigantic cluster of stars forming a disk galaxy. In addition to this theory of the motions of galaxies, he determined the sun is only thirty-thousand light-years from the center of the Milky Way. This places our sun about one-third of the distance from the outer edge of one of the galaxy's arms. He ascertained, too, that the sun makes one complete revolution around the Milky Way's axis once every 225 million years.

Oort's comet cloud theory: *Comets originate in an area beyond the solar system.*

In 1950 Jan Oort identified about twenty comets with orbits so large that it requires many months, or years, for them to complete each orbit around the sun. He believed they originated from a great cloud or reservoir of over one trillion comets, comet material, and assorted objects that swarm far beyond the edge of our solar system. This cloud was still close enough to be affected by the sun's gravity even though it was about one hundred thousand astronomical units (**AU**) in diameter. In comparison, the minor planet Pluto's orbit is only 40 AU in diameter. An AU is the average distance between Earth and Sun. His theory states that these objects in the Oort cloud are "leftover" matter remaining at the edge of the *solar nebula*, the swirling mass of dust and gas that formed the solar system, planets, meteors, and comets. He suggested there were two kinds of comets, both of which were disturbed from their paths within this cloud by perturbations caused by the gravity of a passing (not too close) star. The path of one type of comet follows a hyperbolic orbit or path through the solar system, meaning it makes a wide sweep but not a closed orbit. Therefore, it appears only once as a comet visible to the naked eye or low-powered telescopes from Earth, never to return again. The paths of other comets become very eccentric, but their orbits are closed. They do not follow a circular path through the solar system but rather eccentric ellipses. This is the most familiar type, such as Halley's comet, and the more recent Shoemaker–Levy comet, which smashed into Jupiter on July 11, 1994. More recently, there is evidence that an inner Oort comet cloud exists beyond the planet Neptune. It is believed it contains about one hundred times the number of comets as does the outer Oort cloud, and these inner cloud comets have a more nearly circular orbit, similar to planets, than do the comets in the outer Oort cloud (*see* Figure K5 under Kirkwood for a similar asteroid belt).

OPARIN'S THEORY FOR THE ORIGIN OF LIFE: Biology: *Alexsandr Ivanovich Oparin* (1894–1980), Russia.

The first living organism subsisted on organic substances, not inorganic matter.

How life started is one of the oldest philosophical and biological questions. Charles Darwin's theory of evolution did not include an explanation for the origin of life. The concept that life just "arrived" from nonliving substances was known as *spontaneous generation*. Redi, Pasteur, and others disproved this idea that life "just spontaneously started." In 1922 Alexsandr Oparin was the first to theorize there was a slow accumulation in the oceans of simple organic compounds formed from interacting inorganic compounds. He conjectured that the original living organisms were *heterotrophic* because they did not synthesize their food from inorganic materials, as would *autotrophic* organisms, such as some bacteria and green plants. A more recent theory states that energy-producing elements and compounds self-organized into microcomponents of plant and animal cells (mitochondria and chloroplasts) combined through the process of **autopoiesis** to form simple cells.

See also Margulis; Miller; Oken; Pasteur; Redi; Virchow

OPPENHEIMER'S CONTRIBUTIONS TO THEORETICAL PHYSICS: Physics, *Julius Robert Oppenheimer* (1904–1967), United States.

> *As founding father of the school of theoretical physics in the United States, he was called upon to coordinate the multitudinous effort to produce the atomic bomb.*

(NOTE: The complete stories of the development of the first atomic (neutron) bombs and the life of Robert Oppenheimer are fascinating but too long to be incorporated in this volume.)

Julius Robert Oppenheimer was born in New York City on April 22, 1904. His father was a wealthy German textile merchant and his mother an artist. He entered Harvard University in Cambridge, Massachusetts, at the age of seventeen to study chemistry but soon switched to physics. His studies were interrupted after a period of illness, but he graduated summa cum laude in just three years with an AB degree in 1925. Following Harvard he spent a year at the University of Göttingen where he studied with the German physicist Max Born, who was famous for his work in quantum mechanics. Together they published a well-received paper referred to as the "Born–Oppenheimer approximation" that described the separation of nuclear motion from electronic motion in molecules. Oppenheimer graduated form Göttingen with a PhD in 1927 at the age of twenty-two. He continued his studies at several other European universities before he returned to Harvard for a short time. In 1928 he studied at the California Institute of Technology and, at the same time, also accepted an assistant professorship in physics at the University of California, Berkeley. He spent the next thirteen years dividing his time between these two universities. He is credited with important research in areas of astrophysics, spectroscopy, quantum field theory, as well as nuclear physics. He wrote a paper that was the first to suggest the possibility of black holes in the universe.

During the late 1930s many German physicists who were involved in research regarding the process of nuclear fission and its potential for producing great quantities of energy were concerned that the Nazis might use this discovery to develop some form of bomb. Many migrated to the United States and soon became involved in various nuclear research projects around the country. Many people worked on the various aspects related to the successful construction of the first atomic bomb. These physicists believed that Nazi Germany would use the physics of fission to construct new types of extremely powerful bombs. They convinced one of their own colleagues, Leo Szilard, to contact Albert Einstein, who was then considered the outstanding physicist in the world, to write a letter to the U.S. President Franklin Roosevelt. The letter, which Einstein consented to write, implored President Roosevelt to create at the national level some means to study the feasibility of such a project. Roosevelt, to his credit, recognized the gravity of the plea, and soon after the Manhattan Project was established. The rest is history.

Many people worked on the various aspects related to the successful construction of the first atomic bombs. Oppenheimer and his right-hand man, Robert Serber (1909–1997) of the University of Illinois, determined how neutrons moved in a chain reaction and how much U-235 it would take to form a critical mass required for U-235 to fission and explode. After conferring with colleagues, Oppenheimer confirmed that a fission bomb was feasible and could work. He was also convinced that a single centralized laboratory was needed to manage the research and development required for this task. The various procedures for the tasks involved were carried out in three highly secretive sites: 1) Los Alamos National Laboratory in New Mexico was the main research "think tank" and was assigned the task of forming the bomb cores. It was also the final assembly area for the first bombs. 2) The new town of Oak Ridge was built on farmland in Tennessee. Oak Ridge National Laboratories were responsible for the gaseous diffusion and other processes that were used to separate U-235 from U-228, thus producing fissionable bomb material. 3) The Hanford site produced plutonium for a different type of fissionable bomb that used the element plutonium instead of uranium. This site is located in southeastern Washington State on the Columbia River. In addition, there were other research and development (R&D) sites, including the first atomic pile located at the University of Chicago that proved that fissionable material could be controlled, as well as used as an explosive. These joint efforts were called the Manhattan Project, which spread out over the entire United States (as well as some sites in Canada and England). The project employed over 130,000 people and cost what would be over $20 billion in today's dollars. Overall management of this huge effort was assigned to U.S Army General Leslie Groves (1897–1970) who was responsible for the final production of several atomic bombs. Groves had great respect for the knowledge and abilities of J. Robert Oppenheimer and wanted him as the director of all the research efforts involved in the project. However, due to Oppenheimer's youthful sympathizing with the socialist aspects of communism, as well as his marriage to a suspected communist sympathizer, he was placed under investigation in 1943 by both the FBI and the Manhattan Project's internal security branch, primarily because of his past left-wing associations. Despite these suspicions, General Groves considered him too valuable to lose, and Oppenheimer continued to work on the Manhattan Project through 1945, as well as acting as an advisor on other government-related research agencies after the end of World War II.

Because of his questionable political past and his opposition to Edward Teller's project to develop the hydrogen bomb, which was a nuclear fusion bomb many times more powerful than the atomic fission bomb, Oppenheimer's security clearance was revoked in 1953. He never again received government clearance, even though most of his colleagues and the general public considered him to be a great patriot. He returned to academic life but never forgot the sting and consequences of the government's accusations.

OSTWALD'S THEORIES AND CONCEPT OF CHEMISTRY: Chemistry: *Friedrich Wilhelm Ostwald* (1853–1932), Germany. Friedrich Ostwald received the 1909 Nobel Prize for Chemistry.

Ostwald's theory of catalysts: *Nonreacting foreign substances can alter the rate of chemical reactions.*

Cognizant of the kinetics (movement of particles) of chemical reactions, their speeds, and equilibrium states, Ostwald theorized that certain substances (catalysts), when added to a chemical reaction, can either speed up or slow down the rate of that reaction; but at the same time, the catalyst will not alter the energy relationship within the reaction nor will the catalyst itself be changed. This concept became extremely important in the development of modern technology for controlling a great variety of chemical reactions, including the platinum beads used in the modern catalytic converter in automobile exhaust systems to reduce harmful exhaust gases to less toxic fumes.

Ostwald's law of dilution: *The extent to which a dilute solution can become ionized can be measured with a high degree of accuracy.*

Ostwald's law of dilution is a means for determining the degree of **ionization** in a dilute solution with some degree of accuracy. A dilute solution is one with a small amount of solute (the substance dissolved) compared to the amount of solvent (the substance dissolving the solute). He patented his process, now known as the Otwald process, which is used worldwide to produce nitric acid by oxidizing ammonia.

P

PARACELSUS' CONCEPTS OF MEDICINE: Chemistry: *Philippus Aureolus Theophrastus Bombastus von Hohenheim (Paracelsus)* (1493–1541), Germany.

Iatro-chemistry is superior to herbal chemistry for treating diseases and illnesses.

Early in his career, Philippus Aureolus Theophrastus Bombastus von Hohenheim changed his named to Paracelsus, meaning "equal to or greater than Celsus." Celsus was a first-century Roman physician whom Paracelsus greatly admired. The Roman Galen, the famous herbalist physician, subscribed to the **humoral theory** of disease; his teaching persisted for fifteen hundred years and was considered the authority in medicine during Paraclesus' time. But Paracelsus continually challenged Galen's doctrines as accepted by his contemporary physicians in the early sixteenth century. As a physician, Paraclesus was, in a sense, a compassionate patient advocate. For most of his life and for many reasons, he was an "outcast" in the medical community. One reason was that he usually did not agree with his peer physicians with regard to their accepted methods of practicing medicine. Their disagreements were also based on Paracelsus' concept of viewing the human body from a chemical point of view, not just as a spiritual vessel. Paracelsus' iatro-chemistry (the use of chemicals for medical treatments) was based on his doctrine called *Tria prima*, which was predicated on three basic types of matter: mercury was the spirit, sulfur the soul, and salt the body, with the inflammable sulfur combining the body and spirit into one unit. This, and more, was the basis of medicinal alchemy in the Middle Ages. Alchemy was the study and practice of combining a few basic elements to form the philosophers' stone, considered the key to transmuting base metals (e.g., lead) into gold or to produce the "elixir of life" that was sought as the cure for all illnesses.

Paracelsus was the first link between medieval medical practices and modern scientific medicine and pharmacology. He cured a few powerful men who became his sponsors, which enabled him to continue teaching and to use his unique methods of curing the ill. Paracelsus continued to maintain his belief in astrology, magic, and alchemy but used combinations of chemicals, such as mercury, iron, arsenic, sulfur, antimony, and laudanum (opium), rather than herbs. He was the first physician to try specific remedies for specific diseases and to connect heredity and lifestyle patterns to certain diseases and physical conditions, such as goiter, cretinism, and patterns of syphilis. He criticized his colleagues for their practice of "torturing" the ill by bleeding them, as well as using other inhumane treatments. He denounced local doctors publicly as a "misbegotten crew of approved asses" for their ways of practicing medicine. This attitude, along with the loss of a legal case in which he sued a wealthy citizen for nonpayment of his fee, was used to discredit him. The common people respected him, but after his sponsors died his many enemies in the medical community and universities who threatened his life finally drove him out of the country. For the remainder of his short life, he was a physician to miners in a small town, from whom he learned about metals and minerals, as well as the unique lung diseases endemic to this population. Paracelsus introduced pharmacology, antiseptics, modern surgical techniques, and microchemistry (homeopathy). His work with the miners also qualifies him as the first physician to develop the field of occupational and industrial medicine. He was known for tailoring the dosage of his medications to the amount required to cure his patients. He is famous for a basic biological and medical principle that states: *All things are poisonous and yet there is nothing that is poisonous. It is only the dose that makes a thing poisonous.* Paracelsus' tombstone is a broken marble pyramid located in the cemetery of the Hospital of St. Sebastian in Salzburg in Austria. His epitaph reads, "Here lies buried Philippus Theophrastus, distinguished Doctor of Medicine, who cured dire wounds, leprosy, gout, dropsy, and other contagious disease of the body, and with wonderful knowledge gave his goods to be divided and distributed to the poor."

PARDEE'S THEORY FOR CELL ENZYME SYNTHESIS: Biology: *Arthur Beck Pardee* (1921–), United States.

A mutant gene can induce dominance on a molecule to suppress production of the enzyme beta-galactosidase.

Arthur Pardee and his staff crossed a mutant bacteria cell with normal bacteria, which then became capable of synthetically producing a metabolic enzyme crucial to the growth of living cells. Their process produced synthetic beta-galactosidase without requiring outside stimulation. This led to the production of purines and a better understanding of nucleic acids. Purines are double-ring nitrogenous organic molecules such as adenine (A), guanine (G), thymine (T), and cytosine (C), which form the base pairs of the nucleic acids of DNA and RNA. A new pathway was provided for newly formed proteins that can be stimulated

Arthur Pardee participated in a famous experiment, called the PaJaMo experiment that was first published in 1959 in the *Journal of Molecular Biology.* It was named after Pardee and two of his colleagues, François Jacob, and Jacques Monod, at the Pasteur Institute in Paris who performed a series of conjugations—the mating between "male" and "female" E. coli bacteria where the bacteria traded genes. This resulted in restored systems that began production of beta galactosidase almost immediately after the genetic information enabled the bacteria to produce protein.

by growth factors to duplicate their own DNA, and thus continue to divide. The human immune system T-cells, which fight not only infections but also cancer cells, do not normally reproduce, but with this new technique, it became possible to produce numerous T-cells. Pardee's research advanced the understanding of the immune system, enzymes, T-cells, and the HIV virus infection.

See also Crick; R. Franklin; J. Watson

PARKES' THEORY FOR SEPARATING METALS FROM ORES: Chemistry: *Alexander Parkes* (1813–1890), England.

> *Specific metals can be separated from other metals, as well as from impurities found in common ores, by the use of chemical reactions.*

Alexander Parkes was trained as a chemist but became well known as a metallurgist and an inventor of plastics and held over sixty-six patents in his lifetime. He was aware that in addition to the metals that are found in common ores, there are many impurities as well. Thus each type of ore must be treated individually with different chemicals to extract the desired metals. One of the early systems used mercury to extract gold and silver, which are soluble, from their specific ores. These ancient methods were improved as the nature of elements, particularly metals, were applied to metallurgy. Today, the cyanide process is used to extract gold from its ore. The process is efficient but pollutes the environment with toxic cyanide chemical residues.

Parkes developed an extraction method now known as "the Parkes process" to remove silver from lead ores. It was known for years that some lead ores contained a significant amount of silver, but it could not be separated from the ore because it was not soluble by known processes. Parkes' process used molten zinc to "dissolve" the silver from lead ore. This was possible because molten silver is about three thousand times more soluble in molten zinc than lead. Because lead would not dissolve in molten zinc, the silver was "freed." Today, it is known that all metals are combined with other elements and that other chemicals are required to react with them to free the metals from the impurities in ores. The three process used are classified as follows: 1) *pyrometallurgy* where heat is used as in smelting and roasting the ores, 2) *electrometallurgy* where electricity is used in the process of electrolysis to separate aluminum, calcium, barium, magnesium, potassium, and sodium, and 3) *hydrometallurgy*, where various fluid solutions are used to leach and dissolve metals from their ores. Some examples are when copper oxide and copper carbonate compound-type ores are washed with dilute sulfuric acid followed by additional refining processes.

In addition to his patents in electroplating, Parkes received many other patents in the development of plastics. In 1856 he developed a new material he called "Parkesine" that was the first thermoplastic. It was something like celluloid because it was made from nitrocellulose mixed with camphor and ethanol. His company, that was set up to produce his new plastic as a synthetic ivory, failed because Parkesine was very flammable and even explosive. This is understandable because nitrocellulose is used as "gun cotton" and is related to nitroglycerine. His next venture with associate Daniel Spill (1832–1887), a businessman and chemist, was in the development of "Xylonite," an improved form of Parkesine. This patent was involved in a lawsuit with American inventor John Wesley Hyatt (1837–1920) who developed in 1869 what is known today as celluloid. Spill, who brought the lawsuit for patent infringement, was unsuccessful. However, in 1870 a patent judge ruled that Parkes was the first inventor of the process that produced the plastic (Parkesine) later known as celluloid. It was Hyatt's company, The Celluloid Manufacturing Company in Albany, New York, who would achieve commercial success with celluloid, rather than its original inventor, Alexander Parkes. Because the new celluloid was also flammable and had a tendency to crack, it has been replaced over the years by many improved forms of plastic. Today, celluloid is limited in its use, primarily in table tennis balls.

PASCAL'S CONCEPTS, LAWS, AND THEOREMS: Physics: *Blaise Pascal* (1623–1662), France.

Pascal's concept of a barometer: *The height of a column of mercury decreases as altitude increases due to a decrease in air pressure.*

Blaise Pascal pursued the concept of atmospheric pressure proposed by Evangelista Torricelli's experiment that demonstrated that a 30-centimeter vertical column of mercury could be suspended in a closed tube. Torricelli was the first to theorize that the mercury was not suspended because a vacuum formed inside the closed tube, but rather by the weight of the air outside the tube (*see* Figure T2 under Torricelli). Pascal set out to prove that the height of this column of mercury was dependent on the weight of the air above the mercury in the dish that contained the column of mercury, and that the weight of air pushing down on Earth varied with altitude. He and his brother first measured the exact height of the suspended mercury in the column at the altitude of Paris, France. They proceeded to move the experiment to the top of a high mountain and demonstrated the column fell (was fewer than 30 cm) as the altitude became greater, proving air above a mountain is less dense and thus exerts less pressure on Earth than at sea level. Thus, he not only confirmed Torricelli's concept of air pressure but also discovered that this phenomenon could be used as a crude altimeter. The concept of the barometer can be used to predict weather conditions based on the fact that warm, stormy air is less dense and thus weighs less per square centimeter than cold, clear, denser air. The altimeter's basis is the fact that air becomes less dense as the altitude increases. Thus, the greater the altitude, the less air weighs per square centimeter. The barometer is vital for weather forecasting, and the altimeter is important for determining the altitude of airplanes (*see also* Galileo; Torricelli).

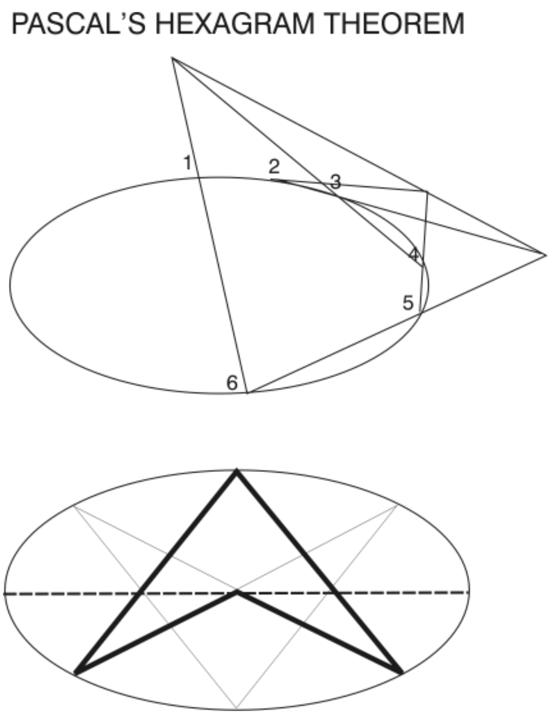

Figure P1. If the lines of a hexagon (six-sided figure) touch the circumference of a circle (conic figure), then the lines of this hexagon can be connected by the lines that meet at a central point inside the conic figure.

Pascal's law of hydraulics: *Pressure applied to a contained fluid is transmitted throughout the fluid in all directions regardless of the area to which the pressure is applied or the shape of the container.*

Blaise Pascal based this law on his work with atmospheric pressure and the demonstration, performed by the Flemish mathematician and engineer, Simon Stevin, that the pressure on a fluid of a given surface depends on the height of the fluid above the surface but not on the surface area of the fluid or the shape of the fluid's container (today we know this as the science of hydrostatics). For example, if you fill two 20-foot vertical pipes with water, one of which is just 2 inches in diameter while the other is 12 inches in diameter, and place equal valve taps at the base of each pipe, the pressure of the water coming out of each tap will be equal because the height of the columns of water coming out of each tap is equal, at least at the start of flow from each tap (but their original volumes or surface areas were not originally equal). Pascal's law of hydraulics basically states that fluids transmit pressure equally in all directions. For instance, the pressure exerted on a confined liquid with a plunger having a small 2-cm cross section will exert a greater pressure on a surface area having a much larger cross section. If the second surface's area is twice as great as the first plunger's surface area, so is the pressure exerted on the second area by the plunger. The original pressure is multiplied by the differences in the areas of the cross sections of the two surfaces. He used this law to develop the hydraulic press, which converts a small force into a much larger force. When a person steps on the brake pedal to stop a car, the hydraulic system converts the small force of the foot on the pedal into the much larger force on the brake discs located on each wheel, stopping the car. This force is transmitted through the hydraulic fluid and tubing system to the brake's mechanism on the car's wheels to create adequate friction of the wheel's brake pads or discs, which then stops the car. In this case, a special oil-like fluid is used instead of water because water would freeze and prevent the hydraulic system from working (*see also* Archimedes).

Pascal's theorem: *If a hexagon is inscribed in any conic section, the points related to where opposite sides meet will be collinear.*

At the age of sixteen Blaise Pascal had already formulated several theorems of projective geometry that later became known as Pascal's theorem. Viewing a diagram of his theorem is

Blaise Pacal was the skinny son of a famous French mathematician. As an infant and young boy, Blaise was considered a mathematical prodigy. At age eleven he discovered Euclid's twenty-three theorems with no help from others, and at age seventeen he published an essay on René Descartes. He also developed what some consider was the first digital calculator to help his father who was an administrator in the local town. He later joined the Port Royal Society, a religious community that was controversial and considered by some to be heretical to the teachings of the Roman Catholic Church. In 1656 a Papal Bull was issued, almost excommunicating Blaise and all the others mentioned in the document. Along with his work on air pressure and hydraulics, he was one of the first to use the concept of probability in calculating events. The concept of probability was not proposed as a mathematical theory until the late 1700s when Marquis Pierre Simon de Laplace arrived at the mathematics involved when calculating win–loss odds in games of chance. For example: If a gambler rolls a pair of die twenty-eight times, and 7 comes up each time, the probability that he will roll a 7 the twenty-ninth time is just as great as is the chance that the next person's first roll will result in a 7. Many gamblers do not completely believe this and consider chance more a stroke of luck. In other words, every roll of the dice has the same chance (probability) of arriving at a specific number as every other roll (assuming the die have not been altered in shape or some other way).

easier to understand than a written statement (*see* Figure P1 for two aspects of Pascal's hexagram theorem).

In essence, the theorem states if a hexagon (six-sided figure) is circumscribed onto a conic figure (touches the outside of the circle or oval), then the vertices of this hexagon (lines connecting the opposite points where the sides of the hexagon meet) can be connected by three lines that meet at a central point inside the conic figure.

Pascal in cooperation with the French mathematician Pierre de Fermat formulated the theory of probability that he related to games of chance, but today it is a very important concept in science and mathematics. He later arrived at several statistical procedures for use in mathematics and physics. He also invented the first mechanical adding machine and strongly believed that scientific discoveries result from empirical observations.

See also Laplace

PASTEUR'S GERM AND VACCINATION THEORIES: Biology: *Louis Pasteur* (1822–1895), France.

Pasteur's germ theory of fermentation: *Fermentation can be inhibited in fermentable (organic) substances by preventing them from exposure to airborne dust particles.*

Louis Pasteur speculated that only living organisms could differentiate between the various shapes of molecules (*molecular dissymmetry*). He concluded that a definite distinction existed between nonliving (inorganic) and living (organic) chemistry. He then studied fermentation and the effects of yeasts on living substances, which he claimed was a chemical reaction involving microorganisms. This prefaced his famous experiment that disproved the ancient concept of the spontaneous generation of life. About two hundred years earlier, Francesco Redi conducted a similar experiment to disprove spontaneous generation, but without the knowledge of the germ theory. Pasteur placed a cooked broth into a sterilized flask structured with a closed curved neck, which prevented air and dust from entering the flask. The broth did not ferment nor develop any bacterial growth. Then he broke off the curved neck, allowing air and dust to enter, which soon caused the broth to ferment. His interest in fermentation was inspired by France's wine and brewery industries, which were unable to control the quality of their wine and beer. Pasteur was asked by these industries to study the problem, which he did, using the results of his famous sterilized flask experiment. He realized "germs" from the air contaminated the wine, causing it to ferment. He also found microorganisms in the lactic acid that result in the fermentation of milk. As a solution, he devised a process whereby the wine was heated but not boiled, and then cooled in closed containers to prevent airborne dust from contaminating the product. He also applied this process of *pasteurization* to milk, which was heated to about 108°F and then quickly cooled. Pasteur also knew that airborne microorganisms also cause some infections; thus he was one of the first to recommend the use of carbolic acid as an antiseptic, the boiling of surgical instruments, and the maintaining of proper hygiene in hospitals.

Louis Pasteur is also known as the father of stereochemistry for his use of the microscope in the discovery of two types of tartrate crystals that are the mirror image of each other. When molecules with the same formula have different arrangements of the same atoms, the molecules are known as **isomers**. Thus, crystals of the same chemical composition can have different geometries. Up to this time only a single type of geometric crystal had been observed. Pasteur then separated the two types of crystals and demonstrated that a special type of plant mold with only one type of molecular structure of the isomer of racemic acid was involved. While investigating why wine and beer eventually soured, he discovered yeasts with two different shapes—one of which formed sour wine and beer; the other formed a good product that did not go sour. This work led to his process known as "pasteurization" that is the process of applying heat to foods (e.g., milk) to kill harmful bacteria, but not hot enough to adversely affect the taste or quality of the food.

Pasteur's vaccination theory: *Attenuated microorganisms from animals with anthrax can be used to inoculate healthy animals, which will prevent the disease.*

This aspect of Louis Pasteur's work is an excellent example of serendipity—an occasion when an unexpected development or insight presents itself to a knowledgeable observer. It seems that after identifying a batch of chicken cholera bacilli under his microscope, he neglected it for several weeks during a hot summer (chicken cholera is similar to but not the same as the waterborne cholera contracted by humans). Even though this was not a fresh batch of his bacteria, he injected it into healthy chickens. These chickens contracted only a mild case of cholera. He then proceeded to infect both the vaccinated group of chickens and a control group (nonvaccinated) of chickens with fresh cholera bacilli. The chickens that received the attenuated (weakened) bacteria contracted only mild cases of the cholera, while the noninoculated chickens died of the disease. Thus, Pasteur discovered how to produce vaccines that could immunize animals against diseases. He then proceeded to heat gently, to about 75°F, the disease-causing bacilli that made sheep, cattle, horses, as well as humans, ill with anthrax. In one experiment he injected twenty-four sheep with the virulent form of anthrax as well as an additional twenty-four sheep that had been immunized with his attenuated bacilli. All twenty-four nonimmunized sheep died; all of the immunized sheep lived. His most famous accomplishment was his treatment of a young boy who had contracted rabies from the bite of a rabid dog. Pasteur developed the antirabies attenuated virus to inoculate the boy who, after several treatments, survived. The concept of vaccination was improved and expanded by others to include inoculations for diphtheria, typhoid, cholera, plague, poliomyelitis, smallpox, measles, and other diseases of humans and animals. Louis Pasteur is known as the father of microbiology.

See also Koch; Lister; Redi

PAULING'S THEORY OF CHEMICAL BONDING: Chemistry: *Linus Carl Pauling* (1901–1994), United States. Linus Pauling was one of the few people to be awarded two Nobel Prizes, the 1954 Nobel Prize for Chemistry and the 1962 Nobel Peace Prize.

> *The nature of chemical bonding of elements and molecular structure can be determined by the application of quantum mechanics.*

Linus Pauling's career covered not only his early work in determining the nature of chemical bonding of atoms, the complex structure of organic molecules and crystals, the nature of oxygen binding to hemoglobin (sickle cell anemia), and vitamin C therapy, but also for activities to halt nuclear testing, for which he received the 1962 Nobel Peace Prize. Pauling used many techniques to study the structure and bonding properties of atoms, including electron and X-ray diffraction of large protein molecules and electromagnetic instruments to assist in determining molecular structure. His pioneering approach was the use of quantum mechanics to describe how electrons are arranged in orbits, how they bond, at what angles they bond, their bonding energies, and the distances between electrons in different atoms that are combined (See Figure S2 under Sidgwick). This was important because, up to this time, quantum mechanics was usually limited to explanations of phenomena at the larger atomic level rather than the subatomic and energy levels. Pauling found that some elements and compounds do not follow the classical valence bonding of single electrons but rather exist in two or more forms through the process of resonance. He made two unique observations. One was the concept of hybrid molecules, which accounted for various shapes of molecules. The other was the concept of resonance for molecules, which explained how some molecules could appear to be somewhat like similar molecules yet have slightly different structures and thus different characteristics. This is how he conceived the idea that oxygen molecules do not bond in a normal way with some types of hemoglobin cells that are "sickle" shaped. The American physician James Bryan Herrick (1861–1954) first discovered sickle cell disease in 1904; Pauling identified its cause as a genetic malformation of blood cells. People who inherit this *molecular disease* often die at an early age because it affects their blood's capacity to carry oxygen to tissue cells. In 1950 Pauling described the structure of the complex protein molecules involved in the chromosomes of cells as an alpha-helix structure, which almost described the double-helix structure of DNA announced in 1954 by James Watson and Francis Crick. Pauling was the first to use quantum mechanics to explain how atoms bond to form molecules, including the concept of *electronegativity*. (Note: Electronegativity is the power of an atom in a molecule to attract electrons to itself, which is dependent on its valence state.) Pauling's concepts that describe the types of atomic bonding are depicted as complex three-dimensional figures.

See also Bohr; Crick; Ingram; Pauli; Watson (James)

PAULI'S EXCLUSION PRINCIPLE: Physics: *Wolfgang Pauli* (1900–1958), Switzerland. Wolfgang Pauli was awarded the 1945 Nobel Prize for Physics.

> *Only two electrons of opposite spin can occupy the same energy level (same quantum number) simultaneously in an atom's orbit.*

Wolfgang Pauli was aware of Niels Bohr's application of quantum theory to the electrons orbiting the nuclei of atoms. At the time, Niels Bohr based his "planetary" structure of electrons orbiting the nuclei on the new concept of quantum mechanics. In cooperation with the German theoretical physicist Arnold Sommerfield (1868–1951), Bohr expanded his "solar system" atom model to include the energy associated with the electrons in different orbits. The quantum aspect stated that each orbiting electron could have only one of three quantum numbers, referred to as n, l, and m. Pauli proposed the concept that required each electron to be one member of a pair of electrons, one of which "spun" around its axis in one direction, while the other spun in the opposite direction. For this situation to exist, he introduced a fourth quantum number for electrons, s, which has the value of $+\frac{1}{2}$ or $-\frac{1}{2}$. The numbers correspond to the spin of each member of the pair. This is the point at which his famous 1924 *exclusionary principle* entered the picture (also referred to as the *Pauli principle of exclusion*). The principle states that no two electrons in an atom may have the same four quantum numbers—*n*, *l*, *m*, or *s*. The spin and exclusion principle, which explained many mysteries related to the structure of the atom, was confirmed a few years later. In other words, if an electron is at a specific energy level in a particular orbit, no other electron can be at that same exact energy level; thus, other electrons are "excluded." In 1930, Pauli identified a particle in the atom's nucleus that he believed was another type of neutron that had no charge and was emitted along with an electron during beta decay of a neutron. The problem was that the new particle was too light to be a neutron. Some years later Sir James Chadwick discovered the actual neutron that exists in the nucleus. Pauli's "neutron" was later verified and renamed by Enrico Fermi as the *neutrino*.

See also Bohr; Chadwick; Fermi; Steinberger

PAVLOV'S THEORY OF ASSOCIATIVE LEARNING BY RESPONDENT CONDITIONING: Physiology: *Ivan Petrovich Pavlov* (1849–1936), Russia. Ivan Pavlov was awarded the 1904 Nobel Prize for Physiology or Medicine.

An unconditioned response is an automatic response resulting from an unconditioned stimulus.

After graduating from St. Petersburg University, Russia, in 1875 with a degree in natural science, Ivan Pavlov attended the Military Medical Academy (also in St. Petersburg). He received his medical degree in 1879 and another postdoctoral degree in physiology in 1883. Pavlov was interested in mammalian physiology and digestion and continued this work in Germany. However, he returned to St. Petersburg in 1890 where he built a physiology research center. Pavlov focused on the physiology of digestion and glandular secretions. He developed surgical skills that involved the separation of a small part of a dog's stomach from the rest of the stomach. This became known as a "Pavlov pouch" from which he could collect samples of the dog's gastric juices. During his research, he observed that the dogs salivated when they became stimulated during feeding—even before the food arrived. This observation led to his lifelong work in the field of the body's reflex systems. His first research involved the study of involuntary reactions to stress and pain that often led to the body's natural response to "shut down" during excessive stress or pain.

During this research on involuntary response to external stimuli,

> Ivan Pavlov's experiments with dogs included a variety of stimuli to the dogs in addition to the well-known ringing of a bell during their feeding. He used a variety of methods of stimulation, including auditory sounds such as whistles, metronomes, tuning forks, and bells. He also used various visual stimuli. The dogs were soon conditioned to salivate at sounds they connected to the sight of their food. Pavlov's research and theories have had a huge influence on psychological theories related to conditioning of human and animal behavior, as well as learning and neurosis. Today, his followers believe that conditioned reflexes are responsible for most of human behavior and psychological disorders. In the 1940s B.F. Skinner (1904–1990), a behavioral psychologist, proposed that human behavior is a set of responses to a person's environment, and through therapy involving behavior modification and training that includes rewards, one's behavior could be "reconditioned." Unfortunately, the theory has also been used as the more controversial "aversion-therapy" where pain is induced by electrical or other stimulation to alter what is perceived as undesirable behavior.

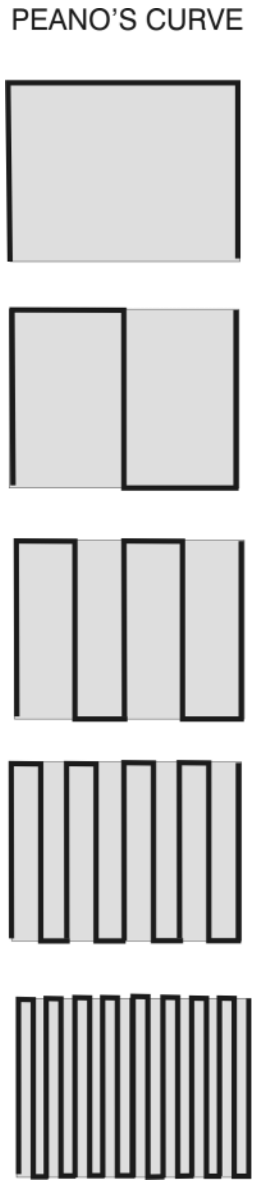

Figure P2. Peano's curve is related to Hilbert's curve and Koch's curve. All versions of continuous curves are based on the concept that many different types of spaces can be completely filled by continuous curves (of many kinds) if space is contained, the curves are connected, and the curve (lines) does not cross itself.

Pavlov performed experiments that showed that the secretion of digestive juices does not require the presence of food in the dog's stomach. The experiment involved allowing the dogs to see, smell, and actually swallow their food, but he prevented the food from going to their stomachs by surgically removing the food from their throats. He then noted that gastric juices were secreted in the stomach just as if the food had entered the stomach. His work on the nerves and gastric glands involved won him the 1904 Nobel Prize in Physiology or Medicine. His papers reporting his research in the early 1900s led to the concept and terms "conditioned reflex" and "Pavlov's dog."

PEANO'S AXIOMS AND CURVE THEOREM: Mathematics: *Giuseppe Peano* (1858–1932), Italy.

Peano's axioms: *The use of symbolic logic and the axiomatic method provide rigor to the theorems of mathematics.*

Mathematical logic is the use of symbols instead of words to explain mathematical statements. This form of logic is sometimes referred to as a *universal language* because universal symbols make working with equations easy for anyone to understand, no matter what language is spoken. Giuseppe Peano conceived nine different logical mathematical axioms. Five of his most famous axioms involved the logic of developing numbers:

1. The figure 1 is a number.
2. Any number that follows 1 in sequence is also a number.
3. No two numbers can have the same successor number.
4. One (1) cannot be a successor to any other number.
5. If 1 has a property and any successor also has that property, so do all numbers.

These axioms are in the form of one of Peano's **syllogisms**, which describe numbers in terms of a set of elements. They are a logical series of statements used to define what a "number" is and is not. Peano claimed that the natural (real) number system can be derived from his axioms. Another of Peano's axioms defined natural numbers in terms of (sets.)

Peano's curve theorem: *There are continuous curves that completely fill all the space inside squares or cubes.*

Peano's continuous curve theorem is based on his idea of the cluster point of a function, which is the basic element for geometric calculus. He defined a curved surface as the length of an arc as compared to the area within a curved surface. He named this geometric function a *space-filled curve*. Peano's curve theorem was revised to include a great variety of types of space that may be completely filled up by a continuously drawn curve, if and only if that space is connected, compact, has a continuous border, and is measurable. For the theorem to apply to enclosed circles and squares, the "curve" or continuous line must not cross itself. For a square, the space-filling curve must have at least three points of multiplicity (*see* Figure P2).

Peano's curve theory introduced the basic elements of geometric calculus and provided a new definition for the length of an arc. It can be used to measure space (areas) within a curve (*see also* Leibniz).

Peano's theory of differential equations: *If f (x,y) is continuous, then the first order differential equation dy/dx = f(x,y) has a solution.*

The solution for the *f* above was first proffered by others. However, just a few years later, Peano showed that it was not unique. As an example, he stated that the differential equation: $dy/dx = 3y^{2/3}$, with $y(0) = 0$.

Peano's interest in mathematics led him to consider the relationships between mathematics and language. He was a pioneer in the field of auxiliary artificial languages, and he created the language called "interlingua" in the early 1900s. He made up his own vocabulary by using words from other languages, including English, French, German, Latin, as well as others. Others carried out further research in this area, including the development of what is known today as the universal language Esperanto.

Two of Peano's greatest achievements are 1) he devised a very efficient notation system for mathematical logic which was clear and easy to understand as well as use and 2) he indicated how simple arithmetic is derived from using a simple logical basis (*see* the above five axioms). Peano is known as the father of mathematical logic.

> Esperanto is a constructed international language that was created in 1887 by an eye doctor, Dr. Ludovic Lazarus Zamenhof (1859–1914), a Polish Jew who lived in what was Germany at the time and is now Poland. Dr. Zamenhof described Esperanto's structure and morphology as based on Romanic and Indo-European languages with contributions from Germanic, Polish, French, and some English words. Although it is not the official language of any country, it is offered as an elective subject in some schools and is learned by many who find it an interesting alternative language. Today it is estimated to have somewhere between one and two million fluent speakers. After the 1911 revolution in China, Esperanto was considered as a replacement for Chinese languages as a possible means to help that country enter the twentieth century. In 1924 the American Radio Relay League used Esperanto as its official language in the hope that it might be adopted by some nations and lead to world peace. Several nonprofit international organizations used it as their official language. Today the largest group to use the language is the World Esperanto Association connected with the United Nations UNESCO organization. Speakers of Esperanto are found mostly in northern and eastern Europe, urban areas of China, as well as regions of Korea, Japan, and Iran. It is spoken also in South America in Brazil, Argentina, and parts of Mexico, as well as on the island of Madagascar in Africa. Its structure is basically pragmatic with new words "invented" by the use of many prefixes and suffixes. The core vocabulary contains about nine hundred roots, which can be expanded by use of the many prefixes and suffixes. It uses just five vowels and twenty-three consonants. It is a relatively easy language to learn and use, and many people and organizations who support its use see it as a possible future world language that will help unite differing nations with a common language to assist them in solving their differences in a more peaceful manner.

PEARSON'S STATISTICAL THEORIES: Mathematics: *Karl Pearson* (1857–1936), England.

It is possible to measure statistically the continuous variations responsible for natural selection.

Karl Pearson developed several important statistical methods for treating data related to evolution. The concept of natural selection as a series of continuous variations was, according to Pearson, a problem dealing with biometrics (using information from living systems to develop synthetic systems). His statistical approach was in direct conflict with that of other scientists, who believed that evolution (natural selection) was a process of discontinuous variations based on breeding as the main mechanism. Among the important statistical concepts that grew out of Pearson's work with evolution are:

- *regression analysis*, used to describe the relationship between two or more variables. In controlled experiments, it is used to estimate the value of the dependent variable (the experimental factor) on the basis of independent variables (controlled factors).
- *correlation coefficient*, the statistical measurement between two variables that is quantitative or qualitative in nature. The measurements are unchanged by the addition or multiplication of random variables. This statistical method expresses measurable (and probable) differences between two events.
- *chi-square test of statistical significance*, which is a means for determining the "goodness of fit" between two binomial populations (two different but related groups), and where each population has a normal distribution. It is a test for determining how far the event is from the statistical mean or how factors for two different events "match."
- *standard deviation* (a term originated by Pearson), the statistical treatment used to determine the difference between a random variable and its mean. It is expressed as the square root of the expected value of the square of this difference.

Many of Pearson's concepts deal with averages. "Mean" is the term we usually associate with "average." It is determined by adding all the values or a set of numbers and dividing the sum by the total number of values—for example, $2 + 4 + 9 + 3 = 18 \div 4 = 4.5$ as the mean (average).

"Median" is the central point in a series (set) of numbers when arranged in order of numbers or value. For the median, there is an equal number of greater (larger) and lesser (smaller numbers above and below the median value). For example, in the sequence 1, 2, 3, 4, 5, 7, 9, 4 is the number halfway between those numbers above and below it, and thus the median. The median may equal the mean, or it may not.

The "mode" is the number most frequently occurring in a set of numbers or values. In the sequence, 1, 1, 2, 2, 5, 5, 5, 6, 8, 9, 12, 16, 25, the mode is 5; it occurs most often in the set. Using the mode instead of the mean can influence the meaning of the data. For instance, if the salaries of one hundred workers and five executives in a company are listed and the mode is used to express a "pseudo-average" salary for company employees, the figure will certainly be lower than if the mean (average) salary is used for the calculation.

See also Darwin; Galton; Mendel

PEIERLS' CONCEPT FOR SEPARATING U-235 FROM U-238: Physics: *Sir Rudolph Ernst Peierls* (1907–1995), England.

Rare uranium-235, which is an isotope of uranium-238, can be separated from uranium-238 by the process of gaseous diffusion.

Rudolph Peierls was familiar with Henri Becquerel's accidental discovery of radioactivity, as well as the Curies' work in separating radium from uranium ore, and Otto Frisch and Lise Meitner's theory of fission of unstable nuclei of uranium. In 1940 Peierls and Frisch collaborated on forming the rare isotope of uranium 235 (U-235) into a small mass that would spontaneously fission, resulting in the production of tremendous energy that might be used to construct a giant bomb. In 1913, Frederick Soddy theorized that when a radioactive element gives off alpha particles (helium nuclei), it changes from one element into a different element with a different atomic number. With the loss of a beta particle (electron), there is also a loss of a negative charge. Thus, the nucleus gains one positive charge, which also makes it a different element. Soddy realized that if neutrons were added to or removed from the nuclei of atoms, the charge would not change (the atomic number would not change), thus the element would still fit its same place in the **Periodic Table of the Chemical Elements**, although it would have a different atomic weight. Soddy called these variations of elements by weight *isotopes*.

Based on the information that uranium contained at least two different isotopes (common U-238 has 92 protons and 146 neutrons, while U-235 consists of 92 protons and 143 neutrons), Peierls and Frisch attempted to separate the two isotopes of uranium. This proved to be difficult because only 1 out of 140 atoms of uranium ore (U-238) is the U-235 isotope. Even so, they made some calculations for the energy output that could result from the fission of U-235 to sustain a chain reaction. For example, once a few atoms started to fission, they would, in very rapid geometric progression, cause all the other nuclei also to fission almost instantly, thus causing a huge explosion. The next problem was how to separate the fissionable U-235 from the stable U-238. This was accomplished by a massive effort using gaseous diffusion. This process converted purified uranium ore into a gas that allows the heavier U-238 to be separated through diffusion filters from the lighter U-235. The first atomic bombs were produced by this method based on the slight difference of atomic weights of U-238 and U-235.

A much simpler and less expensive method of producing a fissionable material was to force uranium-238 nuclei to absorb neutrons inside a nuclear reactor. This nuclear reactor formed neptunium-239 (93 protons and 146 neutrons), which decays into plutonium-239 (94 protons and 145 neutrons). Although plutonium is stable, if it is forced to absorb slow neutrons, it gains atomic weight and thus is radioactive, unstable, and is fissionable. This procedure has become the basis for producing modern nuclear (atomic) weapons.

See also Becquerel; the Curies; Frisch; Meitner; Soddy

PENROSE'S THEORIES FOR BLACK HOLES, "TWISTORS," AND "TILING": Physics: *Roger Penrose* (1931–), England.

Penrose's hypothesis: *Black holes are singularities with "event horizons."*

Roger Penrose, along with Stephen Hawking, applied Einstein's theory of general relativity to prove that black holes are *space-time singularities* (a single event in space-time within a trapped surface). They proposed this concept even though such phenomena have no volume, are infinitely dense, and evolve as space-time events. Penrose's hypothesis is based on the fact that the singularities are not "naked" but rather have an "event horizon," which is the outer limit boundary where all mass, including light once it enters this border area, will be sucked into the black hole by tremendous gravity. The outer rims of black holes (accretion disks) emit visible light but much less than do neutron stars. Penrose stated that things do happen in a black hole. Only a massive, dense object in deep space with an event horizon creates the energy adequate to cause energy (light) to disappear. Particles break down into new particles, one of which would be trapped in the black hole while the other, containing more mass and energy than the original particle, might escape out the bottom. Such an arrangement of matter being changed and compressed on entering one hole and then exiting might be responsible for the birth of new galaxies or universes. If this proves to be correct, the physical concept of conservation of energy will be preserved. Orbiting spacecrafts that carry X-ray instruments continue to explore black holes to learn more about them.

Penrose's twistor theory: *There are massless objects in space existing in "twistor space."*

Penrose's "twistor" theory is a new, complex geometric construct that he developed to explain a synthesis of quantum theory and relativity in space-time. Penrose refers to his theory as "twistor space," where particles have no mass at rest but do exhibit properties of linear and angular momentum (movement) when the particles change position from their point of origin. The particle in space-time may have spin as well as a vector of four dimensions. He developed his theory to replace the Einsteinian theory of relativity and a four-dimensional space-time construct. Twistor theory is a complicated and a not-well-understood or accepted area of research in mathematics and theoretical physics. Penrose's concept of twistors was a result of his investigations into how space-time might be structured. He proposed a wide range of applications for this particular form of mathematics. Even though it is an elegant mathematical formulation, it still remains a mystery and is now considered an "unfashionable" area of mathematical research.

Penrose's tile theory: *"Tiles" can intersect at their boundaries while never overlapping.*

Tilings, also known, as *tessellations*, occur when geometric figures continue to repeat themselves. In other words, tessellations happen when an arbitrarily large plane surface is arranged with nonoverlapping tiles (i.e., the tiles connect only at their boundaries). The tile figures can be constructed by triangles, squares, and hexagons (with three, four, and six possible symmetries) (*see* Figure P3).

A "tiling" figure can never have five sides, such as a pentagon, because it cannot be "folded" so that the edges meet perfectly (i.e., it is not symmetrical). Penrose's tiling also explains the structure of crystals that can have three-, four-, or six-folded rotation symmetry, but not a five-fold rotational symmetry. In 1984 this belief about a five-fold crystal structure being impossible seemed to be disproved when a crystal of an alloy composed of aluminum and manganese was rapidly cooled to form such a crystal. The possible distinction could be that the crystal is three-dimensional while the three, four, and six symmetries were two-dimensional. Tiling may be thought of as a periodic pattern that carries the design into itself. **Fractals** are similar to tiling in that they are self-contained repeating patterns of decreasing size (See Figure W1 under Wolfram). The generating of Penrose's tilings and fractals on personal computers has become a popular exercise for creating geometric designs.

See also Wolfram

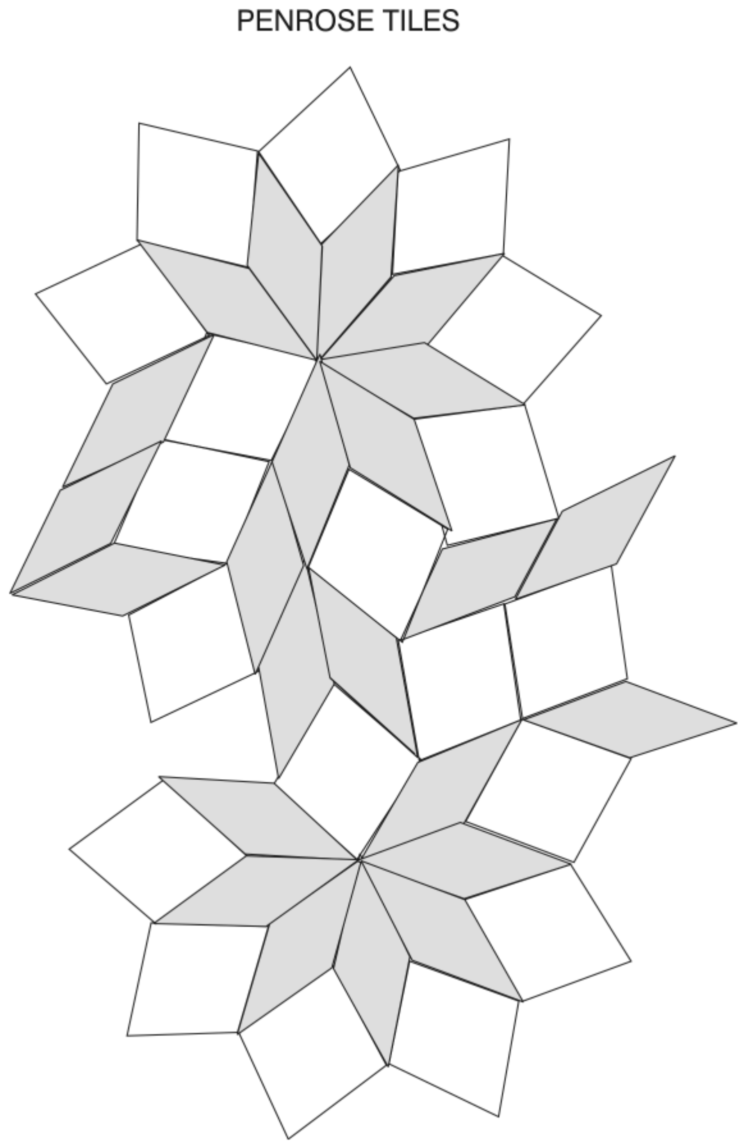

Figure P3. Penrose tiles use the same graphic figure repeatedly, but not overlapping, to cover an arbitrarily large two-dimensional area with a continuous design. The figure may be constructed by using triangles, squares, and hexagons, but may never have 5-sided pentagons. Tessellation is the placing of congruent polygons in a plane.

PENZIAS' THEORY FOR THE BIG BANG: Astronomy: *Arno Allan Penzias* (1933–), United States. Arno Penzias shared the 1978 Nobel Prize for Physics with Pyotr L. Kapitsa and Robert W. Wilson.

> *Background radiation received on Earth from all directions in space is the leftover microwave radiation following the big bang.*

In the early 1960s Penzias and his colleague at Bell Laboratories, Robert W. Wilson, were working with a special radio antenna they designed to detect signals from communication satellites, when they received some unexplained background noise. They continually picked up all kinds of signals—some of this "noise" was generated by the internal electronics of their instruments, some from Earth sources, and some were unexplained. By 1964 they had eliminated much of the other noises but still continued to receive signals near the wavelength of 10^{-3} meters, indicating that the signal was at about 3.6 kelvin. This type of signal proved to be on a timescale much older than Earth itself. Therefore, they concluded it was leftover microwave emission from the big bang origin of the universe about thirteen to fifteen billion years ago. This theory concerning cosmic background microwave radiation is considered an important breakthrough in modern astrophysics.

See also Gamow; Hale; Hawking

PERL'S THEORY FOR A NEW LEPTON: Physics: *Martin Lewis Perl* (1927–), United States. Martin Perl shared the 1995 Nobel Prize for Physics with Fredrick Reines.

A new lepton, the tau particle, generated by a particle accelerator will decay into an electron plus a neutrino/antineutrino, or a muon.

There are two classes of subatomic particles: 1) the *hadrons*, which include the proton and neutron (protons and neutrons along with their "binding" quarks are also considered **fermions**), which have half-integer spin and are quantum individualistic in the sense that they obey the Pauli exclusion principle, and 2) *leptons*, which include four types of particles: the *electron* and the *muon*, along with their two related *neutrinos*. Perl proceeded to use a powerful accelerator to generate a new lepton. It is necessary to use some form of detection device to record the existence of the subatomic particles generated in a particle accelerator before they decay. He generated a record of over ten thousand events, of which only a few of the new particles were detected as he predicted. This new particle turned out to be a new, heavy lepton with more mass than a proton. This caused some problems because the four known leptons are strongly related by symmetry to their four quarks. Therefore, to maintain symmetry, one of the basic constants of physics, a new quark was predicted to match the new lepton. In 1977 this new quark was discovered and named the upsilon particle by Leon Lederman. Thus, both a new lepton and a new quark joined the growing multitude of subatomic particles.

See also Lederman

PERRIN'S THEORY OF MOLECULAR MOTION: Physics: *Jean Baptiste Perrin* (1870–1942), France. Jean Perrin was awarded the 1926 Nobel Prize for Physics.

Einstein's formula for molecular motion can be confirmed by determining the size of molecules.

Jean Perrin was familiar with Scottish botanist Robert Brown's concept that the motion of molecules of water caused the motion of tiny pollen grains suspended in water (Brownian motion) and Einstein's theory that the average distance the pollen particle traveled in the water increased with the square of the time elapsed for the motion. After controlling for conditions of temperature and the type of liquid in which the pollen was suspended, Einstein was able to predict, on the average, how far a particle would travel. However, at the time Einstein made this prediction, there was no way to confirm it. Perrin, who was known for his theories concerning the discontinuous structure of matter and how sediments obtain equilibrium, related these ideas to the importance of knowing the size and energy of molecules. In 1908 Perrin, who had access to a "super" microscope, experimentally controlled and measured the size of molecules as related to molecular movement, thus was able to confirm Einstein's theory of how far a particle should travel in a specific time period. This formula for the size of water molecules was important for the confirmation of the kinetic theory of matter (motion) and Avogadro's number.

Earlier in 1895 Perrin worked on the development of the cathode-ray and X-ray tubes. He was the first to determine that cathode rays must have a negative charge because they were deflected by a magnetic field. He was working on how to determine the ratio of the charge of an electron to its mass, but was superseded in this accomplishment by J. J. Thomson. Perrin is also remembered for his 1913 publication of *Les Atomes*, a comprehensive work that brought together what was then known about atoms and molecules, as well as knowledge about the chemistry of radioactivity, "blackbody" radiation, and other information about atoms and their behavior. This book established the field of atomism.

See also Avogadro; Einstein

PERUTZ'S THEORY OF MOLECULAR STRUCTURE OF HEMOGLOBIN: Biology (Molecular Biology): *Max Ferdinard Perutz* (1914–2002), Austria and England. Max Perutz shared the 1962 Nobel Prize in Chemistry with the British biochemist and crystallographer John Kendrew.

> *The hemoglobin molecule is composed of four separate globin (polypeptide chains) molecules (two alpha and two beta), while the alpha globin consists of 141 amino acids and the beta globin has 146 amino acids that exist near the molecule's surface.*

Max Perutz received his undergraduate education at the University of Vienna. Later in 1940 he received his PhD from Cambridge University in England. He and his first graduate student John Kendrew (1917–1997), the renowned British biochemist and crystallographer, founded a medical research group to continue their research to determine the molecular structure of protein hemoglobin. They used the powerful tool of X-ray diffraction to study this unique hemoglobin molecule. The only limitation of their early procedure was that they were unable to "see" the molecules in three dimensions, thus their model was limited because the actual molecule has over twelve-thousand atoms. To overcome this limitation, they used atoms from several heavy metals (gold and mercury) to replace some of the hemoglobin's atoms, making the X-ray diffraction pattern clearer as to the positions of the atoms in the hemoglobin's molecules. In addition to determining that the structure of the molecule was composed of a tetrahedron consisting of four chains, they determined that four heme groups of atoms existed just beneath the surface of the molecule. (Note: A heme is a prosthetic group consisting of iron—protoporphyrin complex that is associated with each polypeptide unit of hemoglobin.) Perutz also discovered that by exposing hemoglobin to oxygen, it was possible to rearrange the four chains. In time, this discovery was used to explain the mechanism in the hemoglobin molecule that transports oxygen in the blood throughout the body.

Perutz's laboratory was combined with another group at Cambridge to create in 1947 the Medical Research Council Unit for Molecular Biology (MRC), which under his chairmanship grew to over four hundred people. MRC's research led to numerous discoveries and inventions in the area of molecular biology. Max Perutz wrote many books promoting science, including *Is Science Necessary* and *Science is Not a Quiet Life: Unraveling the Atomic Mechanism of Hemoglobin* among others. He is considered one of the founders of the field of molecular biology.

PFEIFFER'S PHENOMENON: THE THEORY OF BACTERIOLYSIS: Biology (Bacteriology): *Richard Friedrich Johannes Pfeiffer* (1858–1945), Germany.

> *Disease-causing bacteria can be destroyed (lysis) by heating them to just above 60°C, which causes them to swell up and burst.*

Richard Pfeiffer was a military surgeon in the German army in the late 1880s. After his discharge, he joined the German biologist and germ-disease theorist Robert Koch at the Institute of Hygiene, which was followed by a professorship at the University of Konigsberg, Germany, then onto Breslau where he did most of his research in bacteriology.

His first discovery, made in 1892, was the bacteria known as *Haemophilus influenzae* (also known as *Pfeiffer's bacillus*). Because the bacillus was found in the throats of flu patients, he at first thought that it also caused the disease. Even in the world's deadliest influenza pandemic that began in 1918 scientists mistakenly believed that Pfeiffer's bacillus caused the disease. This pandemic, commonly called the Spanish flu, killed as many as one hundred million people. It was later determined that the Pfeiffer bacillus was not found in all influenza (flu) patients. Two medical researchers at the Rockefeller Institute in New York City used a filter that contained pores small enough to block bacteria but large enough to allow viruses to pass through. Peter Olitsky (1886–1964) and Frederick Gates (dates unknown) used a Berkefeld filter to filter the nasal secretions of influenza patients. They believed that what passed through was an "atypical" type of bacteria. However, what they really discovered was the influenza virus.

Pfeiffer's theory of bacteriolysis (the destruction of bacteria) resulted from his research involving guinea pigs. He injected live viruses that are responsible for the disease cholera into the peritoneal cavity (the space between the outer wall of the stomach and intestines and the abdominal wall) of guinea pigs that had previously been immunized against the disease. This caused the virus to lose its motility and disintegrate, which he observed under a microscope. He also determined that he could produce the same results if his "bacterioloytic" serum was injected into the peritoneal cavity of nonimmunized guinea pigs. In addition, he discovered the specific bacteria-destroying immune bodies in the bacteria that cause typhus as well as cholera. At the time, several other bacteriologists were working on a vaccination theory for typhus. Another scientist, the British pathologist Almroth Wright (1861–1947) was at first given credit for the discovery of the vaccination for typhus, but after reviewing the literature, it was determined that the credit should go to Richard Pfeiffer.

See also Koch

PLANCK'S FORMULA AND QUANTUM THEORY: Physics: *Max Karl Ernst Ludwig Planck* (1858–1947), Germany. Max Planck was awarded the 1918 Nobel Prize for Physics.

Planck's formula: *$E = \hbar v$; where E = the energy involved, $\hbar$ = Planck's constant of proportionality, and v = the frequency of the radiation.*

For centuries, physicists were puzzled by the two theories of light. During the nineteenth century, some thought the corpuscular (particle) theory and the wave (electromagnetic radiation) theory were inconsistent with the then current theory of molecules and thermodynamics. In the 1860s, Gustav Robert Kirchhoff and other scientists experimented with blackbody radiation, an ideal surface, such as a hollow metal ball with a small hole that absorbs all light, and that does not reflect back any light but rather emits radiant energy of all wavelengths. They found that a body at "red heat" emitted radiation at low frequencies for the spectrum of light waves (infrared and deep-red), and that "white heat" emitted radiation at the higher frequencies at the yellow, green, blue end of the light spectrum. From these data, scientists projected curves on a graph to explain their theories. Max Planck plotted a new set of curves representing these data and advanced a different formula. His formula $E = \hbar v$ explained that energy radiated from the blackbody was specifically in quanta (small bits) of energy, not continuously as previously believed. These quanta were represented by the $\hbar v$ in the formula, where v is the frequency of the radiation and the $\hbar$ is the action of the quanta of energy, which is a proportionality that can only assume integral multiples of specific quantities (quantum theory). The $\hbar$ is now known as *Planck's constant* and is one of the major constants in physics. In other words, the energy of a quantum of light is equal to the frequency of the light multiplied by Planck's constant.

Planck's elementary quantum action theory: *Energy does not flow in an unbroken stream but rather proceeds or jumps in discrete packets or quanta.*

The science of quantum mechanics is based on Planck's theory that energy can only be emitted or absorbed by substances in small, discrete packets he called quanta. This theory has been used and expanded by many scientists. After the 1950s, Planck's quantum theory was used extensively in producing and identifying numerous subatomic and subnuclear particles and energy quanta. There are dozens of other examples in science that make use of Planck's quantum theory. Today many people mistakenly consider a "quantum leap" to be a great stride or large advancement of events or accomplishments. Originally it referred to a very small packet of energy or mass, which may be thought of as a tiny "particle wave" of light or an electron's tiny gain or loss of energy when it moves from one orbit to another (*see* Figure D6 under Dehmelt).

See also Chadwick; Compton; Einstein; Heisenberg; Kirchhoff; Pauli; Rutherford; Schrödinger

POGSON'S THEORY FOR STAR BRIGHTNESS: Astronomy: *Norman Robert Pogson* (1829–1891), England.

> *Pogson's ratio is the interval of star magnitudes that might be represented by a multiple of five magnitudes.*

From ancient times, the magnitude (brightness) of stars was based on what could be judged from Earth. The brightness of stars was ranked in just six magnitudes, the first being the brightest stars (excluding our sun) and the sixth faintest were those just barely visible. Norman Pogson, an Englishman who spent his life in India as an official astronomer, proposed a more rational and useful system to determine the magnitude of stars. He realized the first-magnitude stars were about one hundred times brighter than those in the sixth-magnitude category. From these data he devised a *ratio of brightness* of 2.512. This means a fifth-magnitude star is 2.512 (about two-and-a-half) times as bright as is a sixth-magnitude star. It was soon evident his "ratio" was not adequate for the actual range of brightness to cover all luminosities, so negative magnitudes were introduced. For instance, the sun is a −26.7 magnitude star (as viewed from Earth), and the brightest star beyond the sun is the −1.5 magnitude star, Sirius. The moon has a luminosity of −11.0. Pogson's ratio is still used today, but it is augmented by using the spectrum and colors of stars as recorded on photographic plates, which, through timed exposures, can record stars beyond the twenty magnitude level (*see* Figure H6 under Hertzsprung).

PONNAMPERUMA'S CHEMICAL THEORY FOR THE ORIGIN OF LIFE: Chemistry: *Cyril Andrew Ponnamperuma* (1923–1994), Sri Lanka and United States.

> *It was possible for chemicals and energy existing in the primordial atmosphere to synthesize protein molecules and nucleic acids required for life.*

Cyril Ponnamperuma's theory is based on three processes that must proceed in sequence for life to form from chemical elements and energy. First, the necessary atoms must form into the required molecules. Second, these molecules must combine into self-replicating polymers. And, third, these polymers (large organic molecules) must unite into living cells, tissues, organs, systems, and finally organisms. Ponnamperuma and several other scientists attempted to achieve this process actinically in the laboratory. One attempt exposed a mixture of water, methane, and ammonia to beta radiation, expecting to produce adenine (a purine found in RNA), but in the second and third stages of this process no success was achieved. Another attempt exposed formaldehyde to ultraviolet light to produce a polymer, again without success. Several other scientists have synthetically produced a variety of organic molecules, but none of these experiments met the three stages required in the process of producing life as described by Ponnamperuma.

See also Chambers; Miller

PORTER'S THEORY FOR THE STRUCTURE OF HUMAN GAMMA GLOBULIN: Biochemistry: *Rodney Robert Porter* (1917–1985), England. Rodney Porter shared the 1972 Nobel Prize for Physiology or Medicine with Gerald Maurice Edelman.

> *The antibody known as gamma globulin (IgF) is composed of two identical halves with each half having one long and one short chain.*

After serving in the military from 1940 to 1946 Rodney Porter continued his education and received his PhD from the University of Cambridge in 1948. He worked at

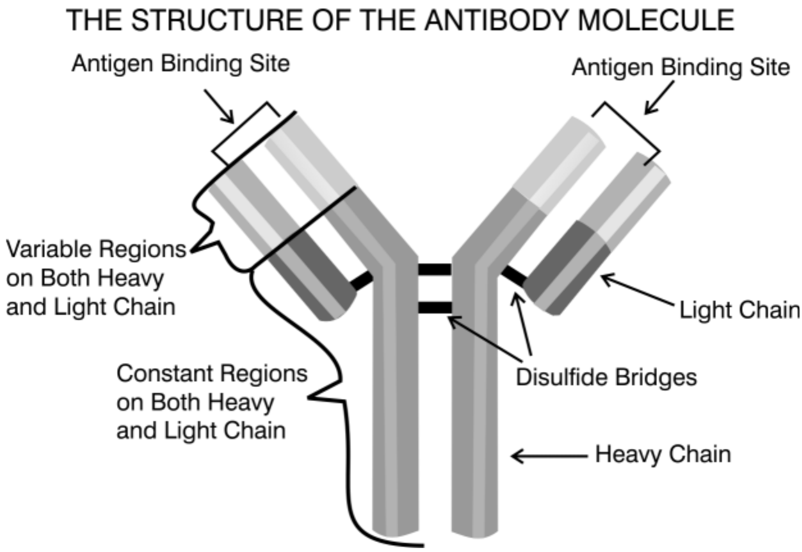

Figure P4. Porter's conception of antibody molecules confirmed what was then currently known (circa. 1960) about antibodies.

the National Institute of Medical Research (NIMR) on the outskirts of London from 1949 to 1960. He then went onto St. Mary's Medical Hospital, London, as the first Pfizer Professor of Immunology. In 1967 he accepted a professorship in biochemistry at the University of Oxford where he developed an interest in antibodies. He was aware of the data resulting from microscopic work related to antibody molecules using electron microscopes. In 1950 while at the NIMR he showed that some antibody molecules could be broken down and still maintain their antigen-binding characteristics. After a decade of research, in 1960 he showed that antibodies contained both "heavy" and "light" protein chains, and that each chain has three distinct regions. Two of these regions on the chains are alike and serve the function of binding antibodies. The two "light" chains form the branches of the "Y" structure in the chain, while the two "heavy" ones form the trunk of the "Y" (*see* Figure P4).

This insight was more-or-less an informed guess as to the actual structure of the molecule of antibodies. However, his scheme confirmed then-known information about antibodies and inspired other biochemists, including Landsteiner and Pauling, to continue his work in the field of immunology.

See also Landsteiner; Pauling

POSEIDONIUS' CONCEPT OF THE EARTH'S CIRCUMFERENCE: Astronomy: *Poseidonius of Apamea* (c.35–51 BCE), Greece.

The circumference of Earth can be calculated by measuring distances between two locations, both on the same meridian circle.

About two hundred years before Poseidonius conceived his method for measuring the circumference of Earth, Eratosthenes of Cyrene measured, simultaneously at the time of the summer solstice, the distance between two distant cities and then used this figure to calculate Earth's circumference as 25,054 miles (the current average circumference of Earth is 24,857 miles). Poseidonius used the figure of 5,000 stadia as the distance between two cities located on the same meridian (*stadia* is an ancient Greek measurement of distance based on the length of the course in a stadium. It is equal to approximately 607 feet, or 185 meters). This meridian encompasses 1/48 of the circle of Earth's circumference. In other words, he projected that the distance between the cities equaled about 1/48 of the distance around the globe at that particular meridian. From this he multiplied 48 times 5,000 to arrive at a circumference of 240,000 stadia, which compared favorably with Eratosthenes' figure of 250,000 stadia. We now assume there are 8.75 stadia to the mile, so the circumference comes out to about 27,000 miles. Poseidonius thought 240,000 stadia was much too large, so he reduced his figure to only 180,000 stadia. About one thousand years later this had unexpected consequences when Christopher Columbus used Poseidonius' figure for a much smaller Earth rather than the one provided by the ancient astronomer Eratosthenes. Therefore, Columbus believed Asia was only 3,000 miles west of the European coast, which made his trip to the New World, which he thought was India, much longer than expected.

See also Eratosthenes

POYNTING'S THEORIES: Physics: *John Henry Poynting* (1852–1914), England.

Poynting–Robertson effect: *Solar radiation causes dust grains within the solar system to spiral slowly inward while increasing their orbital speed.*

Poynting theorized that the sun's radiation caused small particles to become suspended in space and, in time, to spiral closer and closer to the sun, eventually crashing into the sun. He proposed that the radiation pressure upon the particles acted tangentially to the motion of this system of particles. Early in his work in 1903 Poynting considered this phenomenon to be related to the luminiferous nature of the aether that at the time was still believed to be an aethereal substance that filled space and was the medium that carried electromagnetic waves, such as light and radio waves. In 1907 the American physicist, Howard Robertson (1903–1961) correctly described Poynting's theory by ignoring the concept of aether and correctly stating it in terms of special relativity. Since then it has become known as the "Poynting–Robertson Effect."

Poynting vector: *The Poynting vector points in the direction of traveling electromagnetic waves.*

In 1884 Poynting wrote a paper titled "Transfer of Energy in the Electromagnetic Field" that introduced his point theory as the flow of energy through the surface of conductors in terms of electric and magnetic properties. His theory showed that the flow of energy (power) at any point in a conductor may be expressed by a simple formula in terms of vectors indicating the electric and magnetic forces at that point (vectors are scalar quantities that give direction and magnitude). He is best known for this electrical and magnetic phenomena known as the "Poynting vector."

In 1891 Poynting determined the mean density of Earth as well as its gravitational constant by using a well-made instrument known as a torsion balance to arrive at his conclusions that were published in *The Mean Density of Earth* in 1894 and later in 1913 in *The Earth: Its Shape, Size, Weight, and Spin.*

See also Cavendish

PRÉVOST'S THEORY FOR THE EXCHANGE OF HEAT RADIATION: Physics: *Pierre Prévost* (1751–1839), Switzerland.

> *A body that radiates heat energy is independent of the body's environment; and if the body's temperature increases or decreases, it will be dependent on whether radiation is gained or lost.*

Pierre Prévost was originally a professor of philosophy who studied political economy and the fine arts, including poetry. He became friends with the notable French mathematician Joseph-Louis Lagrange, which led him to the study of physics—in particular magnetism and heat. At this time in history, it was believed that heat was a fluid called "caloric," thought to be responsible for heat always flowing from hot substances to cooler bodies. This concept made it reasonable to conceive that cold was also a fluid called "frigoric" and was responsible for the flow of cold to warmer bodies. Some scientists used the example that if a piece of ice is held near a thermometer, the temperature recorded in the thermometer would drop, thus explaining the "frigoric" concept. Prévost's book, *Traite de Physique*, published in 1791, explained his "law of exchange of radiation" and helped clarify the nature of heat. He still believed that heat was a fluid, but a single fluid that flowed from hot objects to cooler ones—never in the other direction. He is the first to describe the concept of equilibrium that explains that if a body is colder than another, it will absorb radiation until its temperature is in equilibrium with its environment's temperature. This means that the cold body does not stop radiating heat but rather radiates just enough heat to reach the point where the radiation is in equilibrium. This became known as "Prévost theory of exchanges" and influenced future generations of physicists to arrive at the kinetic theory of heat based on atomic/molecular motion about a century later.

See also Carnot; Helmholtz; Kelvin; Mayer; Maxwell

PRIESTLEY'S THEORIES OF ELECTRICAL FORCE AND DEPHLOGISTICATED AIR: Chemistry: *Joseph Priestley* (1733–1804), England.

Priestley's theory of electrical force: *The force between two charged bodies decreases as the square of the distance separates the charged bodies.*

Joseph Priestley's friend, Benjamin Franklin, encouraged him to investigate the new phenomenon of electricity. Priestley was the first to measure the electrical force between two charged bodies as related to the distance between them. He calculated that if the distance between the two bodies is increased by a factor of two, the electrical force is decreased by a factor of four. This follows the well-documented general physics principle of the general square law, which was confirmed by other scientists. He also was the first to determine that charcoal (carbon) could conduct electricity. This became an important concept when applied to the new uses of electricity, such as the carbon arc light, the arch furnace, electric motors, and the telephone.

Priestley's dephlogisticated air: *When the oxides of certain metals are heated, they produce an air that has lost its phlogiston.*

Although not the first to experiment with the heating of materials to drive off gases, Joseph Priestley was one of the first chemists to make careful observations and measurements of what happened to the materials he used. He was also the first to try different experiments to help him understand respiration and combustion. In 1771, he hypothesized that when a candle is burned in a closed jar, it consumes much of the "pure" air. Therefore, there must be some way for nature to replenish the air dissipated by burning objects, or else it would all be used up in the atmosphere and none left for respiration. Then he placed a small green plant in the same jar with the candle and found that after several days, the air again would support combustion. Using similar techniques, Priestley isolated several other gases by heating different substances. He produced sulfur dioxide, ammonia, nitrous oxide, hydrogen chloride, and carbon monoxide. He collected a gas, which was known as "fixed air" (CO_2), given off from the vats in a brewery. He then bubbled it through water; the result was carbonated water. Priestley then heated a small amount of mercury in a closed container and noticed that it formed a red "calx" on the surface similar to rust. He proceeded to place a candle, and then a mouse, in this air given off by the heating of this red calx which is the

In addition to being a successful untrained scientist, Joseph Priestley was also somewhat of a religious iconoclast. Priestley's father, Jonas Priestley, was a finisher of cloth and his mother Mary Smith was raised on a farm. He was born in the parish of Birstal near Leeds, England, in 1733. The oldest of six children, he was raised on his grandfather's farm after his mother died in 1741, only to be adopted by his Aunt Sarah who was childless. It was in his aunt's household among many local people with differing views of religion that he was exposed to liberal religion and political beliefs. In elementary school Joseph learned not only Greek and Latin but also Hebrew. As a teenager, he contracted tuberculosis and during his illness considered entering the ministry. As he recovered, he taught himself several other languages as well as geometry and algebra. As his health improved, he began questioning what he had learned earlier about orthodox Calvinism. Instead of attending a religious school, he entered the liberal Daventry Academy in Northamptonshire where dissention in the form of liberal education was taught to followers of natural philosophy and other nonconformist doctrines. Priestley accepted a position as a minister in a church with a poor congregation, staying only three years because his slight speech impediment, along with his acceptance of Unitarianism, made him an unpopular preacher. His next job not only paid more but the congregation was more tolerant of his different theology. Also, with extra income from tutoring in languages, he was now able to buy a number of instruments to aid him in his scientific research. After marriage to Mary Wilkinson, he was ordained in what was known as the ''Dissenting Ministry.'' This was the period when he indoctrinated his students and others into his liberal political theories of law and other fields. With a growing family he moved to a congregation near his birthplace and continued his work with gases and electricity, while at the same time he continued visiting London where he met Benjamin Franklin and other scientists. At this time Priestley turned his interests to politics. He wrote *The First Principles of Government and the Nature of Political, Civil, and Religious Liberty* in 1768. Later in 1774, at the encouragement of his friends, he wrote *The State of Public Liberty in General and of American Affairs in Particular* which was a pamphlet attacking the British role in America. In 1782 he wrote *The History of the Corruptions of Christianity*, followed by *History of Early Opinions Concerning Jesus Christ* in 1786. These books did not make him popular with the public or the ruling politicians because they proposed Unitarian ideas. King George III was convinced that Priestley was an atheist. In 1791 he wrote *A Political Dialogue on the General Principles of Government* which was similar to the *Rights of Man,* written by the American revolutionary Thomas Paine (1737–1809). Many people attacked Priestley for his political and religious views that soon exploded into a mob breaking into his house and destroying books and papers, and even his scientific equipment. He and some members of his family emigrated to the United States where they settled in the northern Pennsylvania town of Northumberland on the Susquehanna River. He is remembered not only for his scientific achievements but also for the establishment of the first Unitarian Church in America.

component mercury oxide. The candle burned much brighter and the mouse lived much longer in this new air that he called "dephlogisticated" air because he believed it lost its "phlogiston." Although Joseph Priestley is credited with the discovery of oxygen, it was Antoine Lavoisier who named *oxygen* from the Greek word meaning "sharp" because, at one time, scientists mistakenly thought that all acids contained oxygen.

See also Franklin (Benjamin); Lavoisier; Scheele

PRIGOGINE'S THEORIES OF DISSIPATIVE STRUCTURES AND COMPLEX SYSTEMS: Chemistry: *Ilya Prigogine* (1917–2003), Russia. Ilya Prigogine received the 1977 Nobel Prize for Chemistry.

Prigogine's dissipative structures: *States of thermodynamic equilibrium for systems are rare. More common states exist where there is a flow or exchange of energy between systems.*

One example Ilya Prigogine used to explain his "dissipative structures" was the solar system. Without the sun's continual bathing of Earth with energy, Earth's atmosphere would soon reach thermal equilibrium, meaning it would reach a sustained very cold temperature because heat always flows to cold, not the reverse. Because the sun provides a steady flow of energy to Earth, this might be thought of as *negative entropy* or, as Prigogine believed, a process that reverses irreversible equilibrium states. His work on irreversible processes is credited with forming a bond between the physical sciences and biology that deals with systems that over time have not obtained equilibrium—life and growth. An example is what happens in living cells as they constantly exchange substances and energy with their surroundings in tissues. The process of thermodynamic entropy is irreversible only if there is no exchange of energy between or among complex systems. Theoretically, some billions of years in the future of the universe, entropy (the complete disorganization of matter) and the irreversible attainment of thermal equilibrium will win out unless a new source of universal energy is forthcoming.

Prigogine's theory of complex systems: *Simple molecules can spontaneously self-organize themselves into more complex structures.*

Ilya Prigogine is known as the grandfather of *chaos theory*, which in the related science of complex structures has a more specialized meaning than the concept of chaos used in ancient as well as modern times. Before the development of Prigogine's theory dealing with dissipative and irreversible processes, chaos theory was thought of as a mathematical curiosity. More recently, chaos theory, as related to complex systems, has had a widespread impact on several science disciplines, particularly biology, but also economics. Chaos deals with initial conditions and how these conditions alter the causes that create problems when trying to predict effects. A classic example is that the knowledge of initial conditions of a weather system does not provide adequate information, down the line, to be able to predict weather with any degree of accuracy (*see* Figure W1 under Wolfram). Weather is a classic complex system where the chaos theory is applicable (to some extent, chaos theory also applies to climate change that might be thought of as weather changes over large geographic [or worldwide] regions that occur over long periods of time).

Prigogine believed that very simple inanimate and inorganic molecules, at least at one time, had the ability to organize themselves spontaneously into higher, more complex organic molecules and organisms. This process must have involved some exchange of energy for the self-organizing molecules to reverse entropy (or, as Prigogine would say, "nonequilibrium thermodynamics"). This is not exactly the same as the old idea of spontaneous generation, but it might be thought of as a modern version of that idea, which he also related to evolution. Ilya Prigogine received a Nobel Prize for his work in nonequilibrium thermodynamics (dissipative structures), which relates to concepts in chemistry, physics, and biology.

See also Margulis

PROUST'S LAW OF DEFINITE PROPORTIONS: Chemistry. *Joseph-Louis Proust* (1754–1826), France.

Elements in a compound always combine in definite proportions by mass.

Based on research that Proust conducted on two tin oxides, two iron sulfides, and several other metals, he found that each compound had a definite proportion of weights between the elements of the compound's molecules. An example is the molecule of water (H_2O). The two elements, hydrogen and oxygen, in the molecules of the compound water always exist in the ration of two atoms of (H) to one atom of (O). (Note: There is a compound of H_2O_2 known as hydrogen peroxide which is not exactly the same as water, but as the oxygen escapes this saturated molecule, it will again be H_2O.) From these experiments he deduced his principle in 1806 stated as "I have established that . . . iron like many other metals is subject to the law of nature, which presides at every true combination . . . that unites with two constant proportions of oxygen." He went on to say: "In this respect it does not differ from tin, mercury, and lead, and in a word, almost every known combustible." Up until this time the French chemist Claude-Louis Berthollet (1748–1822) stated that elements could combine to form compounds in a large range of proportions. The distinction between Proust's concepts and Berthollet's idea is that Proust described the proportional mixtures of elements that make up compounds and Berthollet referred to mixtures and solutions, not compounds. Somewhat later Berthollet admitted that he was not correct and that Proust's law was sound. Also at one time it was thought that a chemical reaction depended on the amount of the original mass of all the reactants—not proportionally. It was the work of the great chemist John Dalton, who many consider the father of modern chemistry, which validated that Proust's law of definite proportions was based on a definite number of atoms of elements joining together to form molecules.

Today, in the field of nanostoichiometric chemistry (viewing reactions at the atomic/molecular levels) chemists have found some minor differences in the proportions of elements in some compounds. For instance, a form of iron oxide known as wüsite can contain between 0.83 and 0.95 atoms of iron for every oxygen atom. Thus, this compound of iron may contain between 23% and 25% oxygen. The small variations are largely due to the various isotopes (molecules of the same element with different atomic weights) that compose the compounds. Also in the field of polymer chemistry the proportion of elements forming a polymer molecule may vary. Some examples are proteins, such as DNA, as well as carbohydrates. Some chemists do not even consider polymers to be absolutely pure chemical compounds, except when their molecular weights are uniform. Proust's research was not accurate enough to detect these slight variations in proportions. Proust was also interested in studying the types of sugars found in some vegetables and fruits. During his research with grapes he discovered that they had the same type of sugar as honey. This discovery later became known as glucose.

See also Dalton

PTOLEMY'S THEORY OF A GEOCENTRIC UNIVERSE: Astronomy: *Claudius Ptolemaeus (Ptolemy of Alexandria)* (c.90–170), Egypt.

> *Earth being the heaviest of all bodies in the universe finds its natural place at the center of all the cosmos.*

Ptolemy collected and compiled a great deal of information from other astronomers. From Aristotle, he gleaned there were two parts to the universe—Earth and the heavens and that Earth's natural place is at the center of the entire universe. He considered Earth the sublunary region where all things are born, grow, and die, whereas the heavens are composed of compact concentric crystal spheres surrounding Earth (*see* Figure P5).

Each shell was the home of a heavenly body arranged in the order of Moon, Mercury, Venus, Sun, Mars, Jupiter, and Saturn, followed by the fixed stars and the "prime

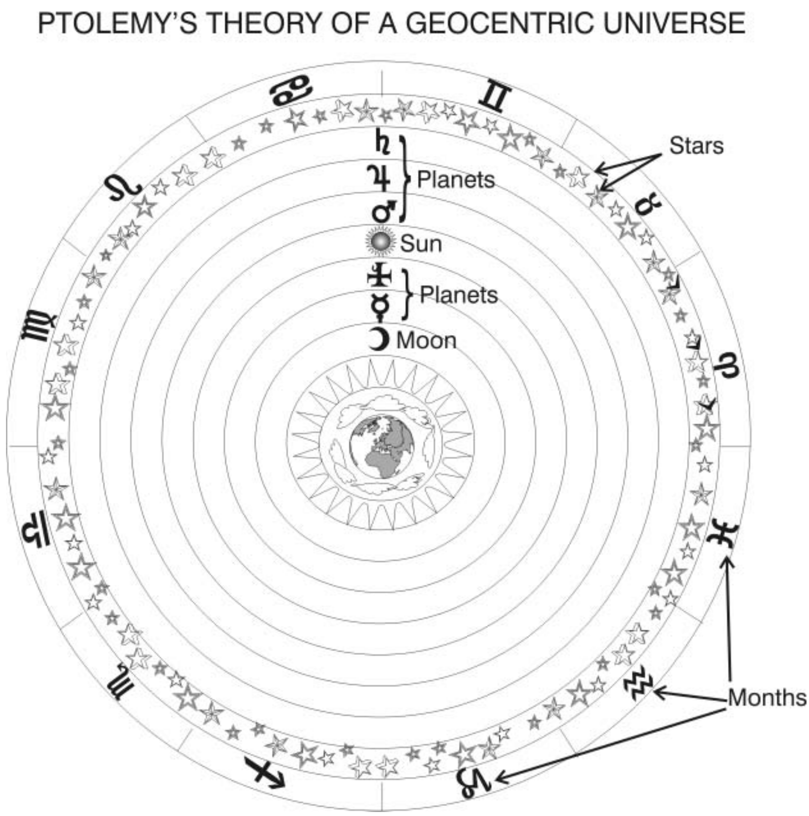

Figure P5. Ptolemy's Earth-centered universe consisted of concentric "shells" starting with the moon's orbit, followed by the inner, then the outer planets, then the stars and finally the "prime mover."

mover," who kept the whole system moving. Hipparchus of Nicaea (c.190–120 BCE), who formulated positions and motions for the planets and moon, was another early Greek astronomer and mathematician who influenced Ptolemy. From this background Ptolemy claimed not only the universe was geocentric, but that all bodies that revolve in orbits do so in perfect circles and at constant velocities, whereas the stars move in elliptical orbits at inconsistent velocities. This required the application of complicated geometry, which Ptolemy used to describe these motions. These three kinds of motions traced the following geometric paths: eccentric, epicycle, and the equant. Ptolemy combined these to form his *Ptolemaic system* for planetary motion. His system was not accurate enough to determine all the motions of heavenly objects, but his system was used by other astronomers for over thirteen hundred years, until in 1514 Nicholas Copernicus developed his first heliocentric model of the universe, which he continued to refine for the next thirty years. It might be mentioned that much of the pseudoscience of today's astrology can be traced back to Ptolemy's planetary motion and the idea that there is some form of physical "rays" emanating from the "heavens" that affects the lives of humans.

Ptolemy's book titled *Optics* was not only his final book but also his best work in which he described a variety of elementary physical principles. He demonstrated that he understood the principles of reflection and **incidence** and to some extent the refraction of light. He even developed tables from his studies of the refraction of rays of light passing from a source of light into water from different angles of incidence.

See also Aristotle; Copernicus; Galileo

PURCELL'S THEORY OF NUCLEAR MAGNETIC RESONANCE (NMR): Physics: *Edward Mills Purcell* (1912–1997), United States. Edward Purcell shared the 1952 Nobel Prize for Physics with Felix Bloch.

> *When the nuclei of atoms are affected by a magnetic field, they absorb energy in a particular radiofrequency range of the electromagnetic spectrum, and then re-emit this energy as the nuclei revert to their original energy state.*

In the 1930s the American physicist Isidor Rabi developed a method of observing a specific atomic spectrum by focusing an electromagnetic beam on the nuclei of atoms and molecules. Rabi thought this phenomenon, later called "nuclear magnetic resonance" (NMR), was caused by his equipment and thus did not recognize its importance. Ten years later Edward Purcell, a young PhD from Harvard, was the leader of a group of researchers at Massachusetts Institute of Technology (MIT), Cambridge, Mssachusetts. His research covered many fields, including radio astronomy, radar, astrophysics, biophysics, and in particular nuclear magnetism. In 1945 while spending time in his laboratory after his regular workday, Purcell observed the phenomenon of NMR. His discovery was based on the work of the Irish physicist Sir Joseph Larmor who determined that the angular frequency of the "spins" of nuclei are proportional to the strength of the magnetic field.

"Nuclear" refers to atomic nuclei of certain elements—not to nuclear energy or the atomic bomb as many people mistakenly believe when they hear the term "NMR."

"Magnetic" as used in this process referred to a magnetic field that is applied to the nuclei.

"Resonance" refers to the oscillating motion of the nuclei caused by the electromagnetic frequency applied to the system.

Edward Purcell of MIT and Felix Bloch of Stanford University expanded this research and found that certain nuclei, when placed in a magnetic field, absorbed energy in the electromagnetic spectrum that relates to the frequencies of radio waves. In addition to absorbing this energy, which caused precession "spins" of the nuclei, the oscillating nuclei gave up this energy and returned to their natural state. With the discovery of NMR it was soon used as a method to study and analyze the exact quantities and quality of various chemical compounds as well as to determine the structure of various materials.

Not long after, others recognized that the single dimension images produced by NMR spectroscopy, although an improvement over other forms of chemical/physical analysis, might be further improved to produce three-dimensional images. First, computed axial tomography (CAT scan) technology was a step in the right direction as others developed what became known as MR and later MRI (magnetic resonance imaging). (Note the "N" for "nuclear" was removed because many people, due to their misunderstanding, did not want to subject themselves to anything related to nuclear energy.) MRI has become a successful diagnostic instrument for viewing the human body in three dimensions. Presently it is also being developed for use as a "real-time" fluoroscope that would enable body processes, such as the flow of blood through veins and arteries, to be viewed as it surges through tissue.

See also Ernst; Kusch; Mansfield; Rabi; Ramsey

PYTHAGORAS' THEOREM: Mathematics: *Pythagoras of Samos* (c.580–500 BC), Greece.

> *The square of the hypotenuse of a right triangle is equal to the sum of the squares of the other two sides of the triangle.*

Pythagoras believed that whole numbers, as well as fractions expressed as ratios of whole numbers, were not only "rational numbers" but also explained the basis of the universe. However, when he compared the sides of a right triangle with the ratio of 1 to 2, the opposite side of the 90° angle (hypotenuse) was an "irrational number." In other words, the diagonal of a square cannot be related to the sides expressed in whole numbers and thus the ambiguity of the square root of 2. The original concept for the Pythagorean theorem goes back one thousand years before Pythagoras to Babylon when the idea was first conceived that any three-sided figure with sides containing the ratio of 3:4:5 would form a 90°right-angle triangle. Proof for the theorem was derived by the Pythagoreans ($a^2 + b^2 = c^2$) with the credit for the proof given to Pythagoras who was the leader of an academic "cult" of mathematicians who believed their work was sacred and should be kept secret. They believed all events and all things can be reduced to mathematical relationships. Their motto was stated as: "All things are numbers," and their secrecy is one reason it is difficult to determine which writings were by Pythagoras and which by his fellow Pythagoreans.

Q

QUANTUM THEORIES: FROM 1900 TO 2008: Over the last century many theoretical physicists from several countries contributed to the development of quantum theories involving particles and waves.

Note: Because there are many scientists involved in the story of the development of quantum theory, this special summary of their contributions is presented. The term *quantum* is derived from the Greek word meaning "how great," or "how much," or "how far." In its modern use it is conceived as referring to the submicroscopic, subatomic, subnuclear phenomena involving unimaginably small particles and energies or waves. Unfortunately, some people and the media confuse the modern use of "quanta" with something very large—they could not be more wrong—even by the ancient Greek concepts. For instance, when an electron is at a specific energy level (orbit) of an atom and either receives or loses energy, the electron will "jump" to a "higher" or "lower" energy level (orbit). This slight jump is referred to as a "quantum leap" and is extremely tiny and does not mean a large shift of movement. There are three crucial dates related to quantum theory. They are as follows:

1900: The concept that atoms are elementary particles of all matter is very old—as far back in time to the Greek philosophers Leucippus of Miletus (c.490–430 BCE) and his student Democritus who are credited with originating the atomic theory that stated nothing could be separated or divided further than the minute atom. From the age of Newtonian classical physics of motion and the development of a more modern concept of the atom based on experiments by Thomson, Rutherford, Niels Bohr, as well as others, it became obvious that the atom was not just a solid ball of matter but rather much more complicated in structure. In 1900 many, but not all, scientists accepted the atomic theory. Even though atoms were defined as indiscrete point particles, it was not understood why and how atoms of different elements differed. For instance, the electron was not discovered until just three years before 1900. No one knew where they were located on or within the atoms, or what their function(s) were.

December 14, 1900, is considered by some the birthdate of the quantum concept of matter and energy. There were many observations of experiments involving the different colors of light emitted by various degrees of heat. For example, a low level of heat produces infrared or red colored light while a higher degree of heat produces bluish colors. The explanation for this is that heat is just the "jiggling" of atoms while remaining in their place. This is explained as the greater the temperature, the faster the jiggling, and thus the greater the heat and the shorter the radiation's wavelengths resulting in the faster jiggling that produces different colors. This also explains the relationship between heat and molecular motion—the faster the molecules move in a substance (solid, liquid, or gas) the hotter the substance—and vice versa. While considering these observation and theories, the German physicist Max Planck arrived at a formula that explained this phenomenon, yet he could not explain why. It just did—and he also stated that jiggling atoms could not assume any of the possible energy levels, but only a level at specific "permissible" values. His formula was announced on December 14, 1900, but his theory did not take the science community by storm. One reason was that his formula did not explain how the energy of a group of jiggling atoms existing at one allowed energy level could change to another energy level if each particle has a specific level of jiggling. What happens in the transition for one level to the next level of energy?

1905: Up to this time Planck's ideas did not seem to fit in with classical physics, but his theories were thought by some to be an extension of "classical mechanics" when only specific values of energy were involved. Some physicists considered that energy consisted of these small quantities, that is, bits of energy that were referred to as being "quantized." After Planck's ideas became more accepted and more was learned about matter and energy, the classical concepts of physics became known as the "old quantum theory." At the age of twenty-six Albert Einstein, drawing on the work of others regarding the nature of heat and the structure of atoms, theorized that a beam of light is quantized. Based on Planck's ideas Einstein proposed that light was quantized and traveled in little packages or bits of electromagnetic energy (light). Gilbert N. Lewis, the famous American physical chemist, suggested the name "photon" for these bits of light quantum. This was accepted by Einstein who went on to propose the nature of these photon packets of light as a duality of the particle-wave theory of light. Another related achievement was Einstein's theory explaining the equivalent nature of mass and energy as in his famous equation $E = mc^2$.

1927: This was the year in which Werner Heisenberg presented the results of his observations of particles, often called his "indeterminacy principle" but more commonly known as the "uncertainty principle." In essence, it states that the more you learn about a particle's energy (momentum) the less you would know about its position in time. And, the reverse is true—using high-powered microscopes, the more you observe a particle's position at a specific time, the less is known about its energy.

Since the discoveries of the electron (1897), the proton (1919), and the neutron (1931), over thirty-five subnuclear particles have been identified in the atom and the atom's nucleus. With the construction of larger, improved, and more powerful circular cyclotrons and linear particle accelerators, they are capable of slamming accelerated "bullet particles" into "target particles" at great forces. This results in the "target particles" breaking or separating into many smaller bits (particles) of matter or bits of energy. It is something like striking a bowling ball with a revolver shot—it may split the ball in a few pieces, but if you hit it with a high-speed artillery shell, it would pulverize the ball into thousands of smaller pieces—all jiggling with specific energies.

Back in the 1920s there were several theories explaining the quantum nature of matter. One was called "matrix mechanics" theory that was based on a complicated form of "mathematical matrices." Another theory was based on the "wave function" of quantum mechanics. And, still another is called "amplitude formation" of quantum mechanics, also known as the "path to integral formulation," or as it was called by Richard Feynman, "the path of least action" that is based on a paper by Paul Dirac. This theory seems to be related to a principle of nature, which says that all actions follow the course of least energy, required for completing that particular process. Based on these several different quantum theories, research into minute bits of particles and energy progressed rapidly. It was not long before it was realized that, mathematically, many of these theories were related and could be applied to solving problems with the very small (atoms and molecules and their particles), as well as explaining very large phenomena including electromagnetism, gravity, and the composition of stars. These theories for quantum mechanics were extended to include relativistic theories, field theories, chemical bonding, and many more problems in various fields of physics. The modern field of quantum mechanics has become a successful theory for science and is based on the research of many physicists. See the index for names of individual scientists who have contributed to quantum theory and who are contained in these two volumes.

R

RABI'S THEORY OF MAGNETIC MOMENT OF PARTICLES: Physics: *Isidor Isaac Rabi* (1898–1988), United States. Isidor Rabi was awarded the 1944 Nobel Prize for Physics.

> *Neutron beams can be used to determine the magnetic moments of fundamental particles such as the electron.*

Isidor Rabi advanced the work of Otto Stern who in 1922 used a beam of molecules to determine the spacing of atomic particles referred to as *space quantization*. Rabi

Isidor I. Rabi's parents were from Eastern Europe, where his father, David, could not earn enough to maintain a family, which led to his emigration to the United States. Because he had no education or skills, he could only find work in New York City's garment district. When he saved enough money, he sent for his family the year after Isidor's birth. With a loan from other Yiddish speaking friends, his father opened a small grocery store. The Rabis soon moved from the Lower East Side to Brooklyn where Isidor discovered science books in the local library. He finally entered Cornell University and graduated with a BA in chemistry in 1919 and later attended Columbia University where he received a PhD in 1927. He spent his entire career at Columbia, with the exception of a two-year tour of Europe. In 1937 he was appointed the first professor of physics at Columbia and held that position until his retirement in 1964. While in Germany in the late 1920s, he worked with Otto Stern and Walter Gerlach whose experiments with molecular beams led to space quantization. When he returned to Columbia in 1929, he invented an atomic/molecular beam system for identifying the magnetic moments of subatomic particles. His work led to theories of quantum electrodynamics, the atomic clock, nuclear magnetic resonance, and the laser. He later was responsible for the planning of CERN—the international physics laboratory and the site of high-energy accelerators and equipment in Europe for the study of subatomic particles.

proceeded to develop a beam composed of various atoms and molecules that he used to produce magnetic resonance (oscillations), which could accurately determine the magnetic moments of fundamental particles. His theory and experiments resulted in the development of nuclear magnetic resonance (NMR), making it possible to measure the energies absorbed and the energies given off by the resonating atoms and molecules, which then can be used to identify substances. The process was revised and improved to produce a better image of human tissue than X-rays, and its name was changed from NMR to magnetic resonance imaging (MRI) because of the mistaken belief that "nuclear" referred to nuclear radiation, rather than the oscillating nuclei of the atoms in the tissue cells of human bodies.

See also Purcell; Ramsey; Stern; Tyndall

RAMAN'S THEORY OF LIGHT SCATTERING: Physics: *Sir Chandrasekhara Venkata Raman* (1888–1970), India. Chandrasekhara Raman was awarded the 1930 Nobel Prize in Physics.

> *A small amount of light of specific frequencies will be reflected from a substance exposed to a direct beam of light of a single frequency.*

Chandrasekhara Raman determined that a beam of light of a single frequency, when striking a substance at right angles, would produce some frequencies different from the original single frequency beam. He further discovered that these new frequencies were specific to the type of material from which the beam was reflected. This became known as the *Raman effect*, which is the exchange of infrared frequency of the light and the material reflecting the light. Although the Raman effect is very weak—about 1/100,000 times less intense than the light of the incident beam—this scattered light of different frequencies can be used to measure the exchange of energy between the light and the substance being examined. The characteristics of the molecules of the examined substance exhibit intensities proportional to the number of scattering molecules that happen to be in the beam of light. This technique can identify specific gases, liquids, and solids. Gases have a low molecular concentration and thus produce a very weak Raman effect. Even so, the Raman effect is a very accurate and effective tool for quantitative and qualitative analysis.

See also Tyndall

RAMÓN Y CAJAL'S NEURON THEORY: Biology: *Santiago Ramón y Cajal* (1852–1934), Spain. Santiago Ramón y Cajal shared the 1906 Nobel Prize for Physiology or Medicine with Camillo Golgi.

> *Neurons are discrete basic cells separate from a network and are the basic structures that function as units of the nervous system.*

Up until about 1800 it was believed that nerve cells were not individual cells as are most other cells of the human body but rather were connected in a mesh or network of cells. In addition, there was the reticularist theory that presumed that nerves continuously communicated. Cajal's theory stated that nerve cells are distinct units consisting of cell bodies, axons, and dendrites, and signals are transferred from cell to cell by the proximity of one cell to the next cell. In other words, they communicate by contiguity. He also proved that neural transmission of signals goes only one way, from dendrites toward axons.

The Italian cytologist Camillo Golgi (1843–1926) developed a silver nitrate stain that could identify specific nerve tissue. Up to this time the stains used for microscopic examinations of body tissues were unable to determine one type of body cell from another. Ramón y Cajal improved Golgi's stain so that it could be "cell specific" as well as being able to identify parts of the cell. He used this technique to examine the structure of the cells, as well as how they connected to each other in the brain. This led to Ramón's neuron theory. Later his research was used to help detect brain tumors. Using his discovery that the neuron was the fundamental unit of the nervous system, coupled with Golgi's staining techniques, Ramón found that nerve cells are discrete and not part of a "mass" of fused cells. Therefore, the Karolinska Institute for the Nobel Prize awarded the 1906 Nobel Prize for Physiology or Medicine to Ramón y Cajal and Camillo Golgi.

RAMSAY'S HYPOTHESIS FOR INERT GASES: Chemistry: *Sir William Ramsay* (1852–1916), England. William Ramsay was awarded the 1904 Nobel Prize for Chemistry.

> *The placement of the inert gas argon in the Periodic Table of the Chemical Elements indicates there will be other similar inert gases, still to be detected, with greater atomic weights.*

Sir William Ramsay followed the work of Lord Rayleigh and Henry Cavendish, both of whom experimented with air and discovered that, after removal of all the nitrogen and oxygen, there appeared to be some "leftover" gas. Rayleigh and Cavendish believed this small amount (1/20 of the original sample) of unidentified gas was the result of contamination by a lighter gas. Ramsay collected this small amount of gas and had William Crookes examine its properties by using spectroanalysis. Ramsay's sample was identified as being the same gas that had been previously detected by the French astronomer Pierre Janssen during a 1868 solar eclipse. In 1898 Ramsay determined this gas was a new gaseous element that was heavier, not lighter than predicted by Rayleigh and Cavendish. He named it *argon* from the Greek word *argos*, meaning "inert." Based on his theory of the placement of argon in the **Periodic Table of the Chemical Elements**, Ramsay predicted there were at least three other heavier inert gases yet to be found. He and several colleagues proceeded to identify helium as the gas emitted from the radioactive decay of uranium. Other inert gases and their meanings are neon (new), krypton (hidden), and xenon (stranger). In 1900 the German physicist Friedrich Ernst Dorn (1848–1916) found that the radioactive element radium gave off a radioactive gas that proved to be the sixth noble gas he called "radon" which is a variation of the word "radium." All six of these gases, also called noble gases, have many uses, including the gas in light bulbs, neon tubing, lasers, photographic speed lights, the decarbonizing of iron during smelting, and as a nonoxidizing gas for welding. Radon, which is the only radioactive inert gas, has limited uses in the treatment of cancer, as well as for detecting leaks and flow rates in liquid pipelines.

See also Cavendish; Rayleigh

RAMSEY'S CHEMICAL SHIFT THEORY FOR IMPROVED MRI: Physics: *Norman Foster Ramsey* (1915–), United States. Norman Ramsey shared the 1989 Nobel Prize for Physics with Hans G. Dehmelt and the German physicist Wolfgang Paul (1913–1993).

Nuclear magnetic resonance using two different radiofrequency fields can identify the chemical shift of molecules by using magnetic shielding.

Norman Ramsey improved Isidor Rabi's nuclear magnetic resonance (NMR) technique by using two different radio frequencies, which result in more accurate measurement of the magnetic effects on atoms. Magnetic shielding encloses the magnetic field within a specified area, preventing external static charges from interfering with the process. The NMR process causes nuclei in atoms and molecules in cell tissues to resonate (vibrate in position) thus revealing the magnetic properties of their atoms and molecules. It can be used to analyze the structure of molecules and their interactions with other nuclei in close proximity. The modern NMR, now called magnetic resonance imaging (MRI), can detect a variety of conditions in the human body. Ramsey also utilized his concept of separate oscillating fields to produce molecular beams in a **maser** to run a very accurate atomic clock. In addition, he worked out a statistical model for negative thermodynamic temperature systems, theorizing the possibility of temperatures below absolute zero (below 0 kelvin or −273.16°C).

See also Dehmelt; Rabi

RAOULT'S LAW: Physics: *François-Marie Raoult* (1830–1901), France.

The amount of decrease in the freezing point of a dissolved substance (as compared to just the solvent) is related to the amount of the dissolved solute as well as to the molecular mass of the solute.

Raoult's law was based on Jacobus Van't Hoff's work on solutions previously done with the optical activity of organic compounds when in solution. Raoult's observations were founded on how and why the freezing point of salt changed when dissolved in water as compared to its being dissolved in an organic solvent. Many organic compounds are optically active in the sense that they rotate the plane of polarized light. Raoult's law is important for understanding the structure and determining the molecular weights of organic compounds.

See also Van't Hoff

RAUP'S THEORY OF CYCLIC EXTINCTION OF ANIMALS: Biology: *David Malcolm Raup* (1933–), United States.

The cyclic extinction rates for individual species of animals peaks every twenty-six million years.

David Raup based his theory of a twenty-six-million-year cycle for the mass extinction of life on Earth on data gathered in cooperation with his collaborator, the paleontologist from the University of Chicago, J. John Sepkoski (1948–1999). Raup believed that fossil evidence of a smooth, evolutionary transition from one species to another, as Darwin claimed, is not convincing. Darwin assumed these gaps in the fossil records would be filled in time and with more exploration. More than a hundred years after Darwin, Raup maintained that the fossil record was still too incomplete to account for a gradual evolution and suggested that general extinctions were caused by extraterrestrial catastrophic phenomena (e.g., asteroids, comets, meteors), not terrestrial disasters, such as earthquakes and volcanic eruptions. Raup's theory is somewhat related to the catastrophic theory proposed by Eldredge and Gould for the extinction of the dinosaurs sixty-five million years ago by an asteroid. When this huge asteroid crashed into Earth, it sent massive clouds of dust and debris into the atmosphere blocking out the sun and resulting in the death of plants, thus depriving animals, such as dinosaurs, of food, ultimately leading to extinction. Raup proposed that Earth has a "companion" star with a twenty-six-million-year orbital period, meaning it returns to the region of the solar system on a periodic basis, bringing with it showers of asteroids that impact Earth. He called this scenario with the companion sun the Nemesis theory. He explained his theory in more detail in his book titled *Nemesis Affair*. Most astronomers reject the Nemesis theory.

See also Agassiz; Cuvier; Darwin; Eldredge; Gould

RAYLEIGH'S LIGHT SCATTERING LAW: Physics: *Third Baron Rayleigh* (*Rayleigh was born John William Strutt)* (1842–1919), England.

> *When energy is removed from a beam of electromagnetic radiation (light), the change in the direction (angle) and wavelength of the emitted radiation is dependent on the scattering nature of the medium through which it passes (i.e., gases or liquids).*

Third Baron John Rayleigh confirmed John Tyndall's theory that light passing through the atmosphere is scattered by small particles suspended in the air. The *Tyndall effect* explains that because water droplets in clouds are larger than wavelengths of light, the clouds appear white. Rayleigh applied mathematics to this concept of scattering to explain why the sky is blue in color. He claimed that light from overhead (midday) is more direct and thus is less scattered (fewer particles for light to travel through) than the light coming from the sun when it is near the horizon. Because there is less scattering of overhead light, the wavelengths of this visible light of the electromagnetic spectrum are shorter and thus appear blue. The same reasoning can explain red sunsets, where sunlight is scattered by more particles and thus the light waves are longer and more toward the red end of the spectrum. Rayleigh accomplished this by determining that the amount of scattering was dependent on the wavelength of light. There are two kinds of scattering: instantaneous, considered "true" scattering, which occurs rapidly when electromagnetic energy is absorbed from the incident beams and then re-radiated; and "delayed" scattering, during which a time lapse between the absorption of the energy and its re-radiation takes place. Delayed scattering causes luminescence. This led to an expansion of the scattering law to include how longer AM radio (amplitude modulation) waves are scattered by the atmosphere and thus can travel around corners and around mountains and buildings, whereas shorter radio wavelengths, such as FM radio (frequency modulation) waves and TV (television) waves, cannot go around buildings and mountains but travel in rather straight lines. Scattering experiments that cause beams of electrons, alpha particles, or other subatomic particles to collide with atomic nuclei have uncovered a great deal about atomic structure and the fundamental nature of matter. These experiments use high-energy particle accelerators designed to scatter the particles and record the resulting paths of collisions. Rayleigh also explained there was another type of wave that followed along a surface whose motion decayed exponentially with the depth of the source from the surface. This type of surface wave is now called a *Rayleigh wave* and is the basis for the development of the science of earthquake detection.

See also Maxwell; Raman; Tyndall

RAY'S THEORIES OF FOSSILS AND PLANT CLASSIFICATION: Biology: *John Ray* (1627–1705), England.

Ray's theories for the origin of fossils: *Fossils were formed by natural processes, not by God.*

John Ray's religion was based on his concept of "natural theology" in which he claimed that if one wants to understand God, one must study His creations of the natural world. Ray proposed several theories about fossils that were considered controversial at that time. There are several other theories for the existence of fossils: 1) some scientists claimed fossils were formed by a creative force on Earth such as earthquakes, floods, and so forth; 2) God was making "models" of different kinds of life; and 3) Satanic forces placed fossils on Earth just to confuse people. Ray's proposed theory was that some organisms possibly washed into big cracks in Earth during the biblical flood. However, he did not believe this was a major cause because this would expose them, and the flood most likely would have washed the fossils away. In addition, most fossils are found in sedimentary beds or stratified rocks. His major theory stated that these organisms were created in the oceans that covered Earth at the time of creation. As the oceans receded, the living organisms were deposited on dry land and then covered with mud and silt, later to become fossilized. His theories that fossils were at one time "natural" living organisms laid the groundwork for future scientists, including Charles Darwin, to explore evolutionary adaptation (*see also* Darwin; Wallace).

Ray's classification system: *Plants and animals can be classified by differences in structure of species rather than by individuals.*

Ray is best known for his classification systems of plants and his later attempts to classify animals by structural similarities and differences. A major contribution was his division of the plant world by distinguishing between *monocotyledons* (based on seeds with a single opening leaf, e.g., grass, corn) and *dicotyledons* (based on seeds with two opening leaves, e.g., trees, beans). Ray also established the basis of classification systems on species, not individuals, and used this system to classify about nineteen thousand different plant species. Ray's classification system influenced Carolus Linnaeus and other taxonomists for several centuries and led others to explore the concept of biological evolution.

See also Agassiz; Darwin; Linnaeus; Lyell; Theophrastus

REDI'S THEORY OF SPONTANEOUS GENERATION: Biology: *Francesco Redi* (1626–1697), Italy.

> *Flies do not generate spontaneously but rather develop from eggs, whereas some other worms and types of insects may appear by spontaneous generation.*

From ancient times through the Renaissance period, it was accepted that some forms of lower life formed spontaneously from nonliving matter. It seemed obvious to most people that garbage generated rats, and food and manure sooner or later spontaneously generated flies. William Harvey was one of the first to contend that vermin, such as flies and rats, do not appear spontaneously but rather come from such vermin breeding and laying eggs. Francesco Redi decided to investigate Harvey's idea and conducted one of the first examples of a controlled experiment. First, he placed cooked meat in eight jars, covering four of them while leaving four uncovered. Maggots and flies developed in the uncovered jars but not the covered ones. He wondered if the air had something to do with the appearance of flies. Next, he placed more meat in another eight jars, covering four with gauze but otherwise leaving them open to air. He left the other four jars uncovered and exposed to air. Redi concluded that maggots do not develop in covered jars that allow air in but keep out flies; therefore spontaneous generation is not a reality, at least for flies. He also concluded that flies must lay eggs too small to be seen in the open jars, and these eggs develop into maggots, which hatch into flies. However, Redi still believed that spontaneous generation was possible for some living organisms, but his controlled experiments did encourage others to perform more definitive experiments.

See also Harvey; Pasteur; Spallanzani

REED'S THEORY OF THE TRANSMISSION OF YELLOW FEVER: Biology: *Walter Reed* (1851–1902), United States.

> *Yellow fever, also known as Yellow Jack, is carried and transmitted by the Stegomyia fasciata (Aedes aegypti) mosquitoes and is not transmitted by contact with sick patients or their clothing.*

The tropical disease of yellow fever was known since ancient times and along with other insect borne diseases, such as malaria and plague, has killed millions of people. In the 1880s the French attempted to dig a canal across the Isthmus of Panama in Central America to facilitate passage between the Atlantic and Pacific Oceans. During the period of 1881 to 1889 one-third of the workers (about twenty-thousand men) digging the canal died from the acute viral disease called Yellow Jack. This and financial troubles drove the French from the area. Following the 113-day Spanish-American War in 1898, troops from the United States that occupied Cuba were devastated by Yellow Jack. The disease takes a few days to develop after being bitten by an infected mosquito. Damage to the liver occurs. The skin turns yellow, followed by high fever, usually ending in fatal coma. The few survivors are often damaged for life. No cure was available, and in 1900 the exact nature of the disease was unknown.

In 1899 Major Walter Reed traveled to Cuba to study the outbreak of disease in the Army's encampments. The following year the U.S. Surgeon General George Miller Sternberg (1838–1915) created a small committee headed by Reed to examine yellow fever as well as other tropical diseases. The committee was known as the U.S. Army Yellow Fever Commission in Cuba. A Cuban doctor Carlos Finlay (1835–1915) was one of the first to theorize that yellow fever was spread by the bite of a mosquito. However, this theory was not accepted by most of the world's doctors. Even so, Reed's Yellow Fever Commission and a contingent of army/soldier volunteers set out to test

Finlay's theories. The first "guinea pig" was Reed's friend and fellow Commission member Dr. James Carroll (1854–1907) who allowed himself to be bitten by a mosquito thought to carry Yellow Jack fever. He became very ill but survived. Other volunteers were not so fortunate. Team member Dr. Jesse William Lazear (1886–1900) died, and Reed himself became very ill. Although he survived, he sustained ill health for the rest of his life. All the army volunteers refused special pay to engage in a definitive test that kept one group in open tents and another group in screened tents with mosquito netting over their bunks. This and other experiments indicated the mosquito's life cycle. It picks up the disease in the first three days that a patient has yellow fever. It then takes twelve days for the disease to incubate in the mosquito's body, followed by the insect's ability to infect other people.

Discovering the cause of the disease was only the first step. Much later a vaccine was developed, and some forms of medication helped the patients, but the main issue for solving the problem was how to get rid of the insect. Major William Crawford Gorgas (1854–1920), 22nd surgeon general of the U.S. Army, eliminated the Yellow Jack mosquito in Cuba by cleaning out all the low areas containing standing freshwater that served as the breeding grounds for the insects. In an attempt to avoid the same disaster that the French encountered in their effort to build a canal, that is, the deaths of thousands of workers from yellow fever, Gorgas was brought to Panama to do the same job he had done in Cuba. This was a challenge because the isthmus region was larger with more breeding grounds for insects and other vermin. In time he succeeded in not only eradicating the Aedes aegypti mosquito, but also the species that causes malaria, as well as the many rats infested with fleas that carried bubonic plague. By the time the canal was finished in 1914 (the U.S. efforts to build the canal began in 1904), the death rate in the area was about half that of the death rate from mosquito-borne diseases in the southern United States. Most of the mosquito-borne diseases in the United States, as well as malaria, yellow fever, plague, and other insect-borne diseases in the third world countries, were eliminated by the use of the insecticide DDT. It proved to be the most effective means for the eradication of disease-causing insects until it was banned in 1972. DDT's ban was based on data contained in the book, *Silent Spring,* by Rachel Carson (1907–1964) who claimed that it was an environmental disaster. Although this reaction resulted in eliminating the use of DDT, it did not eliminate insect-borne diseases that are now responsible for millions of deaths in undeveloped countries.

See also Koch; Pasteur

REGIOMONTANUS' THEORY FOR TRIGONOMETRY: Mathematics: *Johannes Müller von Königsberg (Regiomontanus)* (1436–1476), Germany.

In trigonometry, the use of tables of 1) sines for minutes and 2) tangents for degrees are more useful than using chords.

Johannes Müller, the son of a miller, was a well-known fifteenth-century mathematician, astronomer, writer, and translator of Arabic and Greek science and mathematics. Regiomontanus, known as a young prodigy, was admitted to the University of Leipzig at the age of eleven where he studied for three years. He then entered the University of Vienna in 1450 to study mathematics and astronomy under the Austrian astronomer and mathematician Georg von Peurbach (1423–1461), who became his mentor for life.

Regiomontanus was awarded a baccalaureate degree in 1452 at the age of sixteen. He continued his education at the University of Vienna despite the school's regulation that to receive a master's degree, a student must be twenty-one years of age. When he turned twenty-one, he was awarded his MA degree. In 1457 he was appointed to a position on the faculty at the University of Vienna where he continued working with his mentor, Peurbach. He taught courses on Euclid, perspectives, mathematics, and astronomy, while at the same time he constructed his own astronomical instruments including astrolabes. He became interested in reading and interpreting old science, mathematics, and astronomy books, and making copies for his own use—some of which are still in existence. He had a successful career in several other countries, including Italy and Hungary, in addition to writing several important books. One was *Epitome of the Almagest*, that was begun by Peurbach, in which Regiomontanus not only translated some ancient works, but revised some computations dealing with Ptolemy's lunar theory related to the measurement of the apparent diameter of the moon. While writing *Epitome*, he became aware of the need to revise trigonometry as related to astronomy. In his five-volume book *De triangulis omnomodis libri quinque* he demonstrated a new method of solving triangles as used in astronomical observations. The first and second books of the series were most likely the most important where he, in essence, modernized trigonometry by presenting the definitions for quantity, ratio, equality, circles, arcs, chords, and the sine functions. This was followed by axioms and fifty-six theorems on geometry. The last three books were related to spherical trigonometry as related to astronomy. Later, he calculated two different tables of sines. In his *Tables of directions* he first constructed sine tables in sexagesimal numbers (the number system using the base of 60). Later tables of sines were computed using the decimal base.

In the 1470s Regiomontanus made several important astronomical observations including a lunar eclipse and comets. During this period he also built an observatory and workshop in which to construct his instruments, including dials, quadrants, astrolabes, armillary astrolabes, torqueta, parallactic rulers, Jacob's staffs, among many others that were accurate enough for him to identify what later became known as Halley's comet.

Although instruments of that day were not accurate enough to measure precise positions of the moon that could be used for navigation, Regiomontanus described how the moon's exact positions could be used to determine longitude—a problem for which astronomers throughout the ages had sought an answer. He published these finding in *Ephemerides* using his own printing press. Christopher Columbus and Italian explorer and cartographer Amerigo Vespucci (1454–1512) used this publication to measure longitudes in their travels. Regiomontanus was called to Rome in 1475 by Pope Sixtus IV (1414–1484) to assist in revising the calendar. He died in Rome of the plague that broke out after the River Tiber flooded the region in 1476, although some maintained that he was poisoned.

REICHENBACH'S THEORY OF PROBABILITY BASED ON LOGICAL EMPIRICISM (AKA LOGICAL POSITIVISM): Mathematics and Philosophy: *Hans Reichenbach* (1891–1953), United States.

Reichenbach's theory of probability: *Probability statements are only about measurable frequencies based on three foundations of probability: 1) the law of consistency—only a new probability can be derived from an existing probability, 2) probability rules are given for* *situations where no probability is present, and 3) 1 and 2 are based on the meaning of probability and how it is applied to problems in mathematics and science.*

Reichenbach's theory of *logical empiricism* is an alternative name for *logical positivism*—both are versions of rationalism that itself is a belief that human knowledge includes some knowledge that is not derived directly from empirical observations. His theory is based on the principle of verification, which means that a statement can only have meaning if it is verified by its own methods. Many theological and ethical statements are, in essence, meaningless and only give credence to the beliefs of the person making such statements. He stressed that only scientific, logical, and mathematical concepts can be meaningful and valid.

Reichenbach completed his early schooling in Hamburg, Germany, and later attended several universities in Germany to study engineering, physics, mathematics, and philosophy. Among his teachers were Max Planck, Arnold Sommerfeld, and Max Born. He held several positions, mainly in philosophy, in several universities and was considered a "philosopher of science" and a "scientific philosopher." After Hitler came to power, Reichenbach emigrated to Turkey and accepted a professorship just before papers arrived that expelled him from Germany because of his Jewish background. While in Turkey, he introduced the concept of interdisciplinary courses in science and in 1935 wrote a definitive paper "The Theory of Probability." In 1938 he came to the United States, accepting a position at the University of California, Los Angeles. While there, he published work on the philosophical foundations of quantum mechanics and on space and time. He published *Philosophic Foundations of Quantum Mechanics* in 1944, in which he claims, "[T]here is not any exhaustive interpretation of quantum mechanics which is free from causal anomalies." Hans Reichenbach was a popular teacher because he encouraged his students to ask questions. He also held discussions on a variety of related topics, which students also enjoyed. He was also a prolific writer during these years. In 1947 he wrote *Elements of Symbolic Logic*, and in 1951 the *Rise of Scientific Philosophy*. Two books on which he was working at the time of his death were published in 1954 and 1956: *Nomological Statements and Admissible Operations*, and *The Direction of Time* which distinguishes between the *order* of time (where "A" events occur before "B" events), and the *directions* of time (a process that is irreversible).

REICHSTEIN'S THEORY OF THE CHEMICAL ROLE OF THE ADRENAL GLAND: Biology and Chemistry: *Tadeus Reichstein* (1897–1996), Switzerland. Tadeus Reichstein shared the 1950 Nobel Prize for Physiology or Medicine with Philip Hench and Edward Kendall.

> *Six of the twenty-nine identified chemical steroids are essential to prolong life in animals with damaged adrenal glands.*

In 1946 Tadeus Reichstein isolated and identified twenty-nine **steroid** hormones in adrenal glands. He synthesized aldosterone, corticosterone, and hydrocortisone that he synthetically produced on an industrial scale. He also synthesized the steroid deoxycorticosterone that is used to treat Addison's disease. Earlier, he isolated what is known as adrenocorticotropic hormone (ACTH) or, more commonly known as cortisone that is used in the treatment of arthritis, skin rashes, and joint diseases where inflammation is a major symptom. In 1933 Reichstein also artificially synthesized ascorbic acid (vitamin C), the first vitamin that could be mass-produced.

REINES' THEORY OF NATURAL NEUTRINOS: Physics: *Frederick Reines* (1918–1988), United States. Frederick Reines shared the 1995 Nobel Prize for Physics with Martin L. Perl.

If neutrinos exist in the high levels of radiation found inside nuclear reactors, they should exist in the cosmic radiation.

In 1930 Wolfgang Pauli proposed the theoretical existence of what was called the **neutrino,** a fundamental physical particle that seemed to have no charge and much less mass than the neutron. Pauli claimed that such a particle was necessary to comply with the law of conservation of matter (*see* Figure F2 under Fermi). The problem was that it existed for only a very short period and was no longer detectable when it weakly interacted with other particles. Frederick Reines and his colleague, the American chemical engineer Clyde Cowan (1919–1974), were the first to investigate the neutrino's properties, interactions, and role. First, they confirmed the neutrino's existence as being produced by the high levels of radiation in nuclear reactors. The neutrino is difficult to detect because it travels only a very short distance before weakly interacting with matter and then disappearing. Confirming the neutrino's existence was an extremely difficult task, which Reines and Cowan accomplished in a deep pit near a nuclear reactor in Augusta, Georgia. It was necessary to shield out other high-energy particles and to use tanks of water to slow the neutrinos produced by the reactor so their instruments could record the neutrinos' interactions with other particles. At first, they detected only about three or four events per hour, but this was adequate to prove the existence of neutrinos. Reines and other collaborators were the first to discover neutrinos being emitted from the stellar supernova SN1987A, confirming his theory that neutrinos can be generated from outer space, most likely from the collapse of stars. Reines also found that neutrinos from outer space enter the ground (Earth), from which **muons** are produced. Neutrinos scatter electrons, which produce **antineutrinos**; and oscillating neutrinos can be transformed into different types. Reines' theory of cosmic neutrinos was the forerunner to neutrino physics and neutrino astronomy, which study the interactions of cosmic neutrinos with particles in the atmosphere and their sources in the cosmos. The research related to neutrinos continues as a study of particle physics, which may someday lead to a better understanding of the fundamental laws of conservation of energy and matter.

See also Fermi; Pauli

REVELLE'S THEORY OF GLOBAL WARMING: Chemistry: *Roger Randall Dougan Revelle* (1909–1991), United States.

Energy from sunlight arriving at the surface of Earth as ultraviolet and visible light frequencies is absorbed by rocks, soil, and water at Earth's surface, but not by the small amount of carbon dioxide in the atmosphere at Earth's surface. Thus, this absorbed energy from the surface of Earth is radiated back into space from the surface of Earth as infrared radiation (heat) that is absorbed by carbon dioxide in the atmosphere where it acts somewhat like the glass in a greenhouse and is radiated back to Earth as heat.

Roger Revelle received his PhD degree in oceanography in 1936 from the University of California, Berkeley, while he was employed at the Scripps Institute of

Oceanography (SIO). He became its director from 1950 to 1964, then he moved to Harvard University until his retirement in 1976. While at SIO, he was one of the first scientists to study and verify the magnetic reversals of Earth's magnetic field that led to a better understanding of the tectonics responsible for the spreading of the seafloor and the Great Atlantic Riff. Both are a result of the drifting of continental landmasses. During the 1950s he turned his interest to the new concern of global warming that was just being explored.

In 1896 the Swedish chemist Svante August Arrhenius was the first to suggest that carbon dioxide (CO_2) gas had the capability of absorbing heat and that this could possibly present a problem of warming Earth. He was also the first to propose that an increase in the release of CO_2 into the atmosphere could possibly cause an increase in global temperatures. He proposed that the percentage of CO_2in the upper atmosphere regulated Earth's temperature. Arrhenius believed that this factor was responsible for the past heating and cooling effects on Earth, including the possible cause of the last ice age. Arrhenius also calculated that doubling the amount of CO_2 in the atmosphere could possibly raise Earth's temperature by 10°C. His research led to more studies related to the "greenhouse effect" that led to the current global warming debate and increased political and environmental speculation for pending global disasters. Doubling the amount of CO_2 (a 100% increase) of carbon dioxide as proposed by Arrhenius is not realistic. At the beginning of the twentieth century CO_2 in the atmosphere was about 0.03% of at least eighteen different gases that make up the total atmosphere. This amount of CO_2 is equal to about 325 parts per million volume (ppmv) of the total atmosphere. Today it has risen to about 0.035 percent and may rise to about 0.040 percent or about 400 ppmv, which may raise global temperatures about one degree Celsius by the year 2100. (Note: Some climate experts estimate that the amount of CO_2 in the atmosphere will be greater by the year 2100 at the present rate of release into the atmosphere.) The term "greenhouse effect" is somewhat confusing because the glass roof in a greenhouse does not "radiate" the heat back inside the greenhouse but rather "traps" the heat inside, while CO_2 and other gases in the atmosphere actually "radiate" the heat back to Earth (this might be considered a distinction without a difference). Revelle was partially responsible for the establishment of sites at Mauna Loa in Hawaii and at the South Pole to measure the real extent to which CO_2 and other gases were involved in global warming. The National Science Foundation supported a Greenland Ice Sheet Project that used new techniques to glean information from ice cores form Greenland's ice sheets that gives a climate record of over one hundred thousand years. These cores and others from Antarctica and the Himalayas provide the chemistry of past atmospheres that indicated climate changes as often as a few decades to over periods of thousands of years. Most of Earth's climate changes occurred long before human civilization and the more recent release of greenhouse gases.

There are many causes for the warming effects of Earth's atmosphere in addition to CO_2. First of all, many people do not recognize that Earth is an evolving planet. It is dynamic and undergoes constant physical and geological changes, usually slowly but not always, as in earthquakes. Second, there are other gases that make up the atmosphere, including so-called pollution gases, such as several oxides of nitrogen, and especially the hydrocarbon gas methane that is expelled constantly from vents in the bottoms of oceans as well from gas and oil wells. Methane (CH_4), although not as concentrated as CO_2 in the atmosphere, is many times more effective as a greenhouse gas. There are many factors that account for changes over the centuries of Earth surface temperatures. A few examples are the precession of Earth on its axis; the variations in the sun resulting in the fluxing output of the sun's energy; internal geological changes in the deep oceans and geological structures; and many more, including the results of human activities such as forest destruction, industrial and automobile emissions, and other activities—human and natural.

There is no argument that Earth's surface temperature has increased about 1°C over the last century—a span that has included periods of warming as well as cooling. One problem is the use of advanced computers to "model" the causes and extent of climate change related to global warming. There are a multitude of factors involved in global warming that are not included, or just roughly estimated, that are included in the computer climate modeling programs. These models are improving, but even using weather satellites scientists cannot accurately predict weather for more than a few days, and current methods are still unable to predict accurately the global climate changes for future years or centuries. There are a few solutions to solving the problem of excess CO_2 expelled into the atmosphere. One is that because plants use CO_2 in the process of photosynthesis to make food for all animals, including us, exposing crops to concentrated CO_2 will increase growth and production. This includes trees that act as a huge sink for CO_2, so are the vast oceans that absorb not only CO_2, but other greenhouse gases as well. The oceans sequester a significant amount of excess CO_2 in the forms of many carbon compounds in sea life such as shells and coral. Another method used by some Scandinavian industries is to pump their excess CO_2 deep into the oceans where it is sequestered on the ocean bottom. This process can also be used on land by pumping CO_2 into deep wells or empty gas wells. And another is the market-based proposal of establishing "caps" on industrial pollution with the possibility of selling unused allowances to other entities. Still another possible solution is to develop more machinery and automobiles that use alternative fuels that do not produce CO_2. One example is to extensively use nuclear power to generate electricity. Over the last fifty years or so it has become obvious that even though nuclear power is safer than coal- or oil-produced electricity, nuclear generated electricity is still not accepted by many people.

See also Arrhenius; Rowland

RICCIOLO'S THEORY OF FALLING BODIES: Physics: *Giovanni Battista Ricciolo* (1598–1671), Italy.

A pendulum that beats once per second can be used to confirm Galileo's theory of falling bodies.

Giovanni Ricciolo, an observational astronomer of the seventeenth century, disagreed with many of Copernicus' theories. Even so, he mapped mountains and craters on the moon and was the first to identify Mizar as a double star. He attempted to confirm Galileo's theory that the period of a swinging pendulum is the square of its length. He, and others who assisted him, tried to count the number of swings each day. If the number of swings per day could be adjusted to 86,400 (60 sec./min. × 60 min./hr. × 24 hr./day = 86,400 sec. per day), they would succeed in developing a pendulum that could count seconds accurately. They tired of counting all day and night and so abandoned the project. However, Ricciolo used his pendulum to measure falling bodies. It is assumed that it was either Ricciolo or Simon Stevin, not Galileo, who dropped two balls of different sizes (weights) from the Tower of Pisa. Galileo used inclined planes to slow the descent of the balls and thus was able to time them with his heart pulse beat. Ricciolo used a pendulum as an accurate timekeeper. They both came up with the figure for *g* (the gravity constant) of approximately 9.144 meters per sec. squared that compares with today's figure of 9.807 (about 30 feet per sec. squared).

See also Galileo

RICHARDSON'S LAW OF THERMIONIC EMISSION: Physics: *Sir Owen Willans Richardson* (1879–1959), England. Sir Owen Richardson was awarded the 1928 Nobel Prize for Physics.

> *The kinetic energy of electrons emitted from the surface of a solid is exponentially related to the increase in the emitter's temperature.*

Sir Owen Richardson proposed an explanation for Thomas Edison's observation of the emission of electrons from hot surfaces (Edison effect). The electrons came from inside the solid, which was heated, and escaped from this material when the electrons achieved enough kinetic energy to overcome the "grasp" of the surface of the solid. Richardson's law states: *The electron's temperature (kinetic energy) increases exponentially with the increase of the emitter's temperature.* He claimed that the electrons came from within the solid and eventually escaped if they had achieved adequate kinetic energy (heat) to overcome the energy (heat) barrier existing at the surface of the metal. This is what he meant by **thermionic emission** of metals, which he related to the thermal activity of molecules within a liquid that achieve adequate kinetic energy to pass the surface tension of the liquid resulting in the escape of the molecules from the surface of a liquid during the process of evaporation and boiling. This law became important in the development of electron tubes used in early radio, TV, and radar prior to the days of **transistors** and computer chips.

See also Edison; Shockley

RICHTER'S THEORY OF EARTHQUAKE MAGNITUDE: Geology: *Charles Francis Richter* (1900–1985), United States.

> *Earthquakes can be measured on an absolute scale based on the amplitude of the waves produced.*

Several earthquake scales existed before Charles Richter developed his absolute log scale. In 1902 the Italian volcanologist Giuseppe Mercalli (1850–1914) devised a descriptive scale based on the extent of devastation caused by an earthquake, as well as descriptions of the aftereffects. This was a very subjective means for determining the actual strength of earthquakes because it depended on the nonstandard observations of humans and the types of structures in the region of the earthquake. In 1935 Charles Richter created a scale based on the maximum magnitude of the waves as $\log_{10}$ (logarithm base 10 or a tenfold increase in power for each numerical increase in the scale), as measured in microns. His scale has values of 1 to 9, where 1 is the least damaging and 9 the most damaging. Using logarithms for this scale can be confusing because each increase in number represents a tenfold increase in the power and severity of the earthquake. In other words, an earthquake measured at 5 on the Richter scale is ten times stronger than one with a 4 reading, and a 6 is ten times stronger than a 5 and so on. However, the same 1 unit increase in magnitude corresponds to an increase of approximately thirty-two times the earthquake's energy. It is estimated that for every fifty thousand earthquakes of magnitude 3 or 4, only one of a magnitude 8 or 9 will occur. The United States Geological Survey (USGS) National Earthquake Information Center lists the 9.5 magnitude earthquake in Chile in 1960 as the most powerful earthquake since 1900. The December 2004 earthquake off the west coast of Northern Sumatra that caused the devastating tsunami in that region of the world registered at 9.1.

RIEMANN'S THEORY FOR DIFFERENTIAL GEOMETRY: Mathematics: *Georg Friedrich Bernhard Riemann* (1826–1866), Germany.

> *The curvature for the tensor (multilinear function) of surfaces can be reduced to a scalar number that is either positive, negative, or zero, while the nonzero as well constant cases are models of non-Euclidean geometries.*

Riemann geometry (also known as elliptical geometry) is a form of non-Euclidean geometry. Non-Euclidean geometry differs from two of Euclid's original postulates. Euclid's 5th Postulate deals with parallel lines, whereas Riemannian geometry states that there are no parallel lines. Euclid's 2nd Postulate states that a straight line can be extended to infinity, whereas Riemannian geometry states that all straight lines are of the same length. Another example that most mathematics students learned in geometry classes was that Euclid's geometry states that the sum of the three angles for any triangle will always total 180°. Conversely, Riemann's non-Euclidean geometry states that the sum of the angles in a triangle may be greater than 180°. Thus, Riemann's version was used to explain Einstein's theory of general relativity that includes the concept of curved space.

Riemann made contributions to pure mathematics and analytical mathematics that are related to various areas of physics. Several examples are given below. (Note: A more detailed explanation of Riemann's mathematical concepts is beyond the scope of this book.)

1. *Riemann's zeta function* is an important concept in number theory, primarily because of its relation to the distribution of prime numbers. It also has applications in physics, probability theory, as well as applied statistics. The following are the most commonly used values in the Riemann zeta function:

   (x) = 1 + (1/2)^x + (1/3)^ x + (1/4)^ x +.... etc.,
   Only where *x* = *1*; and,
   if *x* > *1*, then it is a finite number; and,
   if *x* < *than 1* then it is an infinite number.

2. *Riemann integral* is a branch of mathematics that involves real analysis by using approximations for areas. In other words, taking better and better approximations, in time, will result in the exact area under a curve. In essence, the

Riemann integral is the sum of the partitions under the curve as they get finer and finer and the sections under the curve become smaller and smaller where the limit is zero (this is something akin to Archimedes' "squaring the circle" by using polygons to arrive at a better approximation for pi).

3. *The Riemann hypothesis* is related to the *Riemann zeta function* that is explained in 1) above that was first introduced by Euler. However, it was Riemann who generalized its use. Hence, it is known as the Riemann hypothesis which is the most famous problem in mathematics that has never been solved. Many young mathematicians have tackled aspects of this hypothesis either by evaluations of the Riemann zeta functions or calculating the distributions of zeros in the zeta functions The current record of calculation of the amount of zeros has been verified to 10^{13} zeros.

See also Euler; Gauss

ROBBINS' THEORY FOR THE POLIOVIRUS: Biology: *Frederick Chapman Robbins* (1916–2003), United States. Frederick Robbins shared the 1954 Nobel Prize for Physiology or Medicine with American virologists John Enders and Thomas Weller (1915–).

Because the poliovirus can multiply outside nerve tissue, it can exist in other tissue as well.

Frederick Robbins' medical background included collaborating with the U.S. Army to find cures for diseases caused by viruses and parasitic microorganisms. In 1952, Robbins and his colleagues grew the virus that caused poliomyelitis in cultures produced outside a living organism. Up to this time, it was thought the poliovirus could exist only in nerve cells of the central nervous system. They proved this particular virus could live in tissue other than nerve tissue, leading to the theory that the virus survives in body tissue and later attacks the central nervous system. This research resulted in the development of vaccines and new techniques for culturing and detecting the poliovirus that may be dormant in body tissue and later attack the central nervous system.

See also Delbruck; Enders; Sabin

ROBERTS' THEORY OF SPLIT GENES: Biology: *Richard J. Roberts* (1943–), England. Richard Roberts shared the 1993 Nobel Prize for Physiology or Medicine with American microbiologist Phillip A. Sharp.

The DNA of prokaryotic cells becomes messenger RNA, which acts as a template to assemble amino acids into proteins.

Prokaryotic cells have very primitive, poorly defined nuclei, and their DNA has no membrane surrounding them. Some examples are blue-green algae and some primitive bacteria, such as *Escherichia coli* whose primitive nuclei have a single chromosome with only about three million DNA base pairs. Because amino acids require about nine hundred DNA base pairs to form proteins, this prokaryotic type cell should be able to produce about three thousand different proteins. This is in comparison with cells of mammals, called *eukaryotic cells*, which have a well-defined nucleus and contain about four billion DNA base pairs and can produce over 3 million proteins—many more than mammals need. Roberts found that part of the DNA of the prokaryotic cells with no nuclei can split into separate messenger RNA capable of producing proteins. Roberts' simple explanation of the structure of primitive prokaryotic nuclei made the study of the formation of RNA as genetic messengers for the DNA much easier than simply studying the very complex RNA and DNA of mammals. Roberts' theory advanced a better understanding of how amino acids form proteins within the human body.

See also Crick; Sharp; Watson (James)

ROCHE'S "LIMIT" THEORY: Astronomy: *Edouard Albert Roche* (1820–1883), France.

> *A satellite of a planet cannot be closer than 2.44 radii of the larger body without disintegrating.*

In 1850 Edouard Roche proposed what is now known as the *Roche limit*, based on the concept that if a satellite and the planet that it is orbiting are the same density, there is a limit to their proximity to each other without the satellite, or both, breaking up under the force of gravity. The Roche limit explains the existence of the rings of the planet Saturn. Because the outer ring of Saturn is only 2.3 times the radius of Saturn, it might have been a solid satellite that came too close and broke into fragments. The Roche limit also explains why these many small chunks of matter did not re-form into a solid body orbiting Saturn. The orbit of Earth's satellite (moon) is many times the distance of 2.44 radii (the Roche limit) of Earth, thus there is little chance for it to be affected by gravity to the extent it would break into fragments.

See also Cassini; Schiaparelli

RÖENTGEN'S THEORY OF X-RAYS: Physics: *Wilhelm Conrad Röentgen* (1845–1923), Germany. Wilhelm Röentgen received the first Nobel Prize for Physics in 1901.

> *Cathode tubes are capable of sending unknown and undetectable rays to screens, thus causing fluorescence.*

In 1895 Wilhelm Röentgen experimented with a Crookes' tube (a high-voltage gaseous-discharge tube), which produces cathode rays, which produce fluorescence when focused onto a sensitive screen, and detected an unknown form of radiation (*see* Figure C6 under Crookes). He noticed that a cardboard coated with a yellow-green crystal fluorescent material, $BaPt(CN)_4$ (barium cyanoplatinite), located in another part of the room, also was fluorescing when the tube was in operation, even though no rays were directed toward it. He concluded that because **cathode** rays can travel only a very short distance, they must originate from some unknown radiation. Thus, he called them X-rays (also known as Röentgen rays in his honor). He continued to study X-rays, recording accurate descriptions of their characteristics as listed below:

- X-rays had a much greater range than cathode rays.
- X-rays traveled in straight lines but may also be scattered in straight lines from their source.

- X -rays were not affected by magnetic fields or electrical charges.
- X-rays could pass through cardboard and thin metal sheets. Most materials, except lead, are transparent to some degree.
- X-rays could expose photographic materials.
- X-rays passed through the human hand and outlined the bone structure.
- X-rays are longitudinal vibrations (waves), whereas light consists of transverse vibrations.

The discovery of X-rays did not solve the issue of the particle–wave duality nature of light, which was being explored at that time. Rather, it complicated the dilemma because some characteristics of X-rays are similar to light rays and some are not. The use of X-rays became important in the study of crystal structures, as well as in medical diagnosis, and later led to the discovery of radioactivity. Röentgen and his assistant were subjected to excessive exposure to X-rays; both died from radiation poisoning.

See also Becquerel; Curies

ROMER'S THEORY FOR THE SPEED OF LIGHT: Physics: *Olaus Christensen Romer* (1644–1710), Denmark.

The motion of Earth to or away from Jupiter can be used to establish the speed of light.

In the 1670s while examining the records of Giovanni Cassini who had determined Jupiter's rotational period and its distance from Earth, Olaus Romer noticed the figures varied depending on whether Earth and Jupiter were approaching each other in their orbits or receding from each other. There was a difference of ten minutes from the time Jupiter's four then-known moons went behind the planet (were eclipsed) while at the same time Earth's orbital path was *proceeding* in the direction of Jupiter, and when Jupiter's major moons were next eclipsed as Earth's orbital path was *receding* from Jupiter. This ten-minute difference was the amount of time it took the light from Jupiter to reach Earth from these two different distances between Jupiter and Earth. This provided the necessary data for Romer to calculate the speed of light since Cassini had previously determined the distance of Jupiter from Earth. In 1676, Romer announced his theory for establishing the fundamental constant of the speed of light as 140,000 miles per second, which is only about 75% of today's figure of 25,000 kilometers per second (about 186,000 miles/sec.) This was the first proof that light has a finite speed.

See also Cassini; Michelson

ROSSI'S THEORY FOR COSMIC RADIATION: Physics: *Bruno Benedetti Rossi* (1905–1994), Italy.

The charge on cosmic rays can be detected by the influence of Earth's magnetic field.

Cosmic rays were first detected in the early 1900s, but little was known about them except they were a form of high-energy, penetrating radiation. In 1930 Bruno Rossi tested his cosmic ray theory using the east–west symmetry concept. Earth's eastward and westward magnetic fields would act differently on incoming cosmic rays due to the direction of the fields' motions. Rossi set up several Geiger counters (radiation detectors) on a high mountain, facing some eastward and facing several westward, so they could detect and count the cosmic rays coming from outer space from different directions as Earth rotated on its axis. He found an excess of 26% of cosmic rays coming eastward toward Earth. Thus, he concluded they were mainly composed of positive protons and other positive particles, along with some electrons. These were all high-energy particles coming from the sun and possibly supernovae (stars). Later, Rossi believed X-rays must also originate from astronomical bodies in outer space but were not detectible on Earth because they were all absorbed by the atmosphere. In the 1960s, Rossi was one of the pioneers in the use of rockets that carried instruments to detect cosmic X-rays above Earth's atmosphere. He found some X-rays originating from the Crab Nebula, the Scorpio constellation, and many other sources beyond the solar system. Currently a special telescope is orbiting Earth, detecting X-rays leftover from the big bang.

ROWLAND'S THEORY OF CHLOROFLUOROCARBONS' EFFECTS ON THE OZONE: Chemistry: *F. Sherwood (Sherry) Rowland* (1927–), United States. Sherry Rowland shared the 1995 Nobel Prize in Chemistry with two other atmospheric chemists Paul J. Crutzen from the Netherlands and Mario J. Molina from Mexico for their efforts in identifying the threat of chlorofluorocarbons on Earth's atmosphere.

Rowland's theory for CFCs effects on ozone: *Chlorofluorocarbons will decompose in the upper atmosphere, releasing chlorine, which reacts with and breaks down ozone molecules:* $Cl + O_3 \rightarrow ClO + O_2$, *and* $ClO + O \rightarrow Cl + O_2$ *under the influence of UV.*

Rowland's theory is based on one type of reaction of oxygen atoms proposed in 1930 by the British astronomer and geophysicist Sydney Chapman (1888–1970) as a sequence of oxygen to ozone and then reversed as: $O + O_2 \rightarrow O_3$; then $O_3 + O \rightarrow 2O_2$. In the early 1970s, Sherry Rowland and his postdoctoral student, Mario J. Molina, began investigating the possible effects of chlorofluorocarbons (CFCs) on the ozone. In the laboratory setting they were able to work out the reaction as $Cl + O_3 \rightarrow ClO + O_2$, and $ClO + O \rightarrow Cl + O_2$, with a net result of $O_3 + O \rightarrow 2O_2$. In this reaction the *Cl* is a free chlorine atom, O_3 is a form of oxygen molecule called ozone, and O is a nascent oxygen atom, while O_2 is a regular oxygen molecule. This reaction is driven by ultraviolet radiation (UV) striking the CFC molecules and separating out the chlorine atoms that collide with the ozone molecules that then bond with one of the ozone's oxygen atoms forming chlorine monoxide (ClO). In the second reaction, the chlorine is regenerated (freed) to start the process all over again, but some of the oxygen atoms in the second reaction can also combine with the oxygen molecule to re-form the ozone molecule. It takes only a relatively small amount of the CFCs to start the reaction because the chlorine (Cl) in the CFCs can be used over and over again. The question that has not yet been settled is whether this laboratory reaction is the same as what actually happens in the 15- to 30-mile-high **ozone layer**. As the amount of CFCs entering the atmosphere increased after the 1970s, there was a detectable decrease in the ozone layer over Antarctica, but not much of a "hole" over the North Pole. The thickness of the ozone layer has always been cyclic and is always thinner over the equator because this is the area where it is generated and then spreads out to the polar regions. Because refrigeration and air-conditioning used most of the CFCs, these industries in the United States and most of Europe have eliminated their use and are substituting less reactive substances, such as hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). (However, many underdeveloped countries continue to use CFCs.) Experts claim that these and about eighteen other possible HFC substitutes will not cause **global warming** and ozone depletion because they do not contain free chlorine and will decompose in the lower atmosphere. Research continues for even better substitute fluids for refrigeration and air-conditioning use.

See also Arrhenius

RUBBIA'S THEORY OF INTERMEDIATE VECTOR BOSONS: Physics: *Carlo Rubbia* (1934–), Italy. Carlo Rubbia shared the 1984 Nobel Prize for Physics with Simon van der Meer, the Dutch accelerator physicist at CERN.

> *Intermediated vector bosons might be produced in super energy accelerators by using colliding beams of protons and antiprotons that hit each other head on.*

The history of the discovery of elementary particles found in atoms begins with J.J. Thomson's discovery of the electron in 1897, followed by the discovery of the nucleus of the atom in 1911 by Ernest Rutherford and the realization that the nucleus of the hydrogen atom consisted of a single proton. The discovery of the neutron in 1932 was somewhat more difficult because it has no electrical charge. The model of the atom (except for the element hydrogen) was soon determined to contain a nucleus consisting of three types of particles: the positive protons, neutral neutrons, and negative electrons. This model did not last long as additional elementary particles were found in the nuclei of atoms. They became so numerous that they soon were described by a single theoretical name called the Standard Model that includes *quarks* and *leptons* and how they interact within three types of forces known as the *strong*, *weak*, and *electromagnetic* forces (so far the force of gravity is not included in the Standard Model). Gauge bosons are force-related particles that are not the same as quarks and leptons. The Standard Model, although useful, does not identify the mass of elementary particles. So far, the lightest of elementary particles that have mass are electrons and the heaviest so far discovered is the top quark that weighs about two hundred thousand times that of the electron.

Two classes of elementary particles are described by the statistics that are based on two cases. First, is the Fermi–Dirac statistics that apply to fermions (lepton and quarks). According to the Pauli exclusion principle, no two fermions are allowed to occupy the same quantum state at the same time. Second, is the Bose–Einstein statistical rule that states they are the particles known as bosons, which are elementary particles not affected by the Pauli exclusion principle (the boson is named after the Indian [Bengali] mathematical physicist Satyendra Nath Bose [1894–1975], who provided the foundation for the Bose–Einstein condensate). That means that there is no restriction on the number of particles that can exist in the same quantum state. In essence, fermions compose the structures of atoms and nuclei of atoms, whereas bosons are related to forces that interact with fermions. Some examples of bosons that provide these forces are: photons, gluons, and the W and Z particles. Several other particles have been described by unique and somewhat exotic statistical behaviors. Some of these exotic particles are mesons that consist of pairs of quark–antiquark and baryons as quark triplets. Some of the more elusive particles cannot be classified due to their very short lifetime existence, thus they leave no tracks in bubble or cloud chambers, and they cannot yet be detected.

Carlo Rubbia was involved with a new type of particle accelerator at CERN that used intersecting storage rings that cause beams of protons accelerated in one direction and antiprotons beams accelerated in the opposite direction to collide with each other with tremendous force. Using this colliding accelerator enabled Rubbia to discover *intermediate bosons,* which are particles approximately one hundred times heavier than regular protons.

See also Dirac; Einstein; Fermi; Higgs; Rutherford; Thomson

RUBIN'S THEORY OF DARK MATTER: Astronomy: *Vera Cooper Rubin* (1928–), United States.

Galactic rotation indicates there is more mass in galaxies than is visible from Earth.

Vera Rubin studied spiral galaxies by measuring the rotational velocity of their arms by using the Doppler shift that indicates that the light from a body moving away from the viewer will appear redder, and when moving toward the viewer, it appears bluer. In addition, Kepler's law of rotation of bodies in space states that the velocity of a rotating body decreases with the distance. When the gravitational constant is applied to a revolving mass, the following equation should apply: $v^2 = GM/r^2$, where v is the velocity, r is the radius of the orbiting mass, M is the mass, and G is the gravitational constant. Rubin found this equation did not apply to some spiral galaxies because they increased their speed with distance and their mass seemed much too low. She interpreted this to mean the mass had to be there but that it was not visible from Earth. She called this unseen mass **dark matter.** Rubin also concluded that over 90% of all the matter in the universe does not emit much radiation and thus is dark and relatively "cold" in the sense that no light or infrared (heat) radiation is detected. Finally, she concluded there are more dark galaxies than luminous ones. In addition, she believes there has to be much more matter than can be seen because it is required to provide the gravity to hold galaxies together so they do not "fly apart." Solving the puzzle of dark matter may lead to an understanding of the fundamental nature of the universe. Most astronomers accept her concept of dark matter although more research is still required to completely understand our universe.

See also Doppler; Kepler

RUMFORD'S THEORY OF RELATING WORK TO HEAT: Physics: *Count Benjamin Thomson Rumford* (1753–1814), England.

A specific amount of work can be converted into a measurable amount of heat.

Benjamin Rumford was impressed by the amount of heat generated by the process of boring out holes in metal cannon barrels even when water was used to cool the operation. Rumford was familiar with the old concept of "caloric" as being the property within substances that was released by friction or by forcing it out of solids in some way. Some scientists said the boring process "wrung out" the caloric from the metal; others said all those fine shavings created the heat. Rumford had a different theory. He believed heat was generated by the mechanical work performed and proposed there was a conservation of work (friction) and heat (motion or energy). This was one of the first concepts of the conservation of matter and energy and that heat involves motion of some sort (kinetic energy). Several other developments furthered Rumford's theory. These and other theories led to the laws of conservation of mass, energy, and momentum. Rumford invented the **calorimeter**, which measures the amount of heat generated by mechanical work.

See also Joule; Lavoisier

RUSSELL'S THEORY OF STELLAR EVOLUTION: Astronomy: *Henry Norris Russell* (1877–1957), United States.

> *Based on the correlation of the magnitude of stars to their types, stars evolve through stages of contraction from hot giants, to smaller stars, and finally into cold dwarfs.*

In 1913 Henry Russell published the results of his research relating the classification of stars by type to their brightness (magnitude). At about the same time another astronomer, Ejnar Hertzsprung, produced similar data. Their combined data were placed in graph form, known as the Hertzsprung–Russell diagram, which depicts a main sequence of stars as distinct from supergiants, giants, and white dwarfs (*see* Figure H6 under Hertzsprung for a depiction of their graph). Russell was the first to use the terms "giant" and "dwarf" to describe groups of stars. He was also the first to use photographic plates to record stellar **parallax** and to measure a star's luminosity. The diagram depicts the concentration of the supergiants and giants (located in the upper right of the graph) that in time become hot stars in the main sequence, followed by their collapse under the force of gravity to form cool, white dwarfs (located in the lower left of the diagram). Russell developed a method for measuring the size and orbital period for stars as well as their spectra. His work enabled other astronomers to determine galactic distances for stars that were beyond the parallax technique for making measurements. His work also led to new theories for stellar evolution.

See also Hertzsprung

RUTHERFORD'S THEORIES OF RADIOACTIVITY/TRANSMUTATION AND ATOMIC STRUCTURE: Physics: *Baron Ernest Rutherford* (1871–1937), New Zealand.

Rutherford's theory of radioactivity and transmutation: *Radioactive substances emit three different types of radiation by which one element is changed into a different element.*

Baron Ernest Rutherford was one of the first to explore the emissions of polonium and thorium, in addition to radium. In 1899 he discovered there were two different types of radiation emissions from these mineral elements that he referred to as *radioactivity*. He named one type of radiation *alpha*, which would cause ionization but could be stopped by a piece of paper (helium nuclei). The other he named *beta*, later known as high-energy electron emission, which was not ionizing but somewhat more penetrating than beta radiation. He then determined there was a third type of radioactivity, which was characterized by high energy, deep penetration, and highly ionizing, but was not affected by a magnetic field, which he named *gamma rays*. Rutherford used this knowledge to devise an unusual theory, called *atomic transmutation*, which almost sounded like the

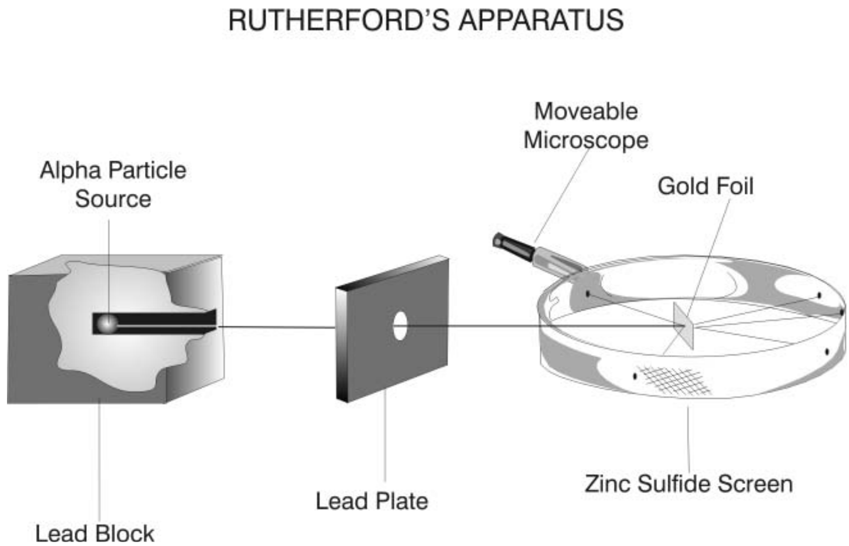

Figure R1. Rutherford's apparatus' arrangement to shoot alpha particles into a small sheet of gold foil that scattered a few particles but allowed most of them to go straight through without hitting any gold nuclei.

old alchemists' dream of the philosophers' stone that was able to change lead into gold. Rutherford's idea stated that as some of these radioactive particles were emitted from their source element, the mass and charge (number of protons) of the original atoms were changed to become a different element. Rutherford and Frederick Soddy confirmed this theory with experiments using radioactive thorium that decayed into another active form, which they called *thorium-X*, which resulted when a series of chemical and physical changes converted one type of atom into another. This was known as *transmutation*. As a result, Rutherford became most interested in the alpha particles and their effect on substances.

Rutherford's theory of atomic structure: *The atom, which is composed mostly of ''empty space,'' has a mass that is concentrated in a very small, dense, central particle that contains a charge.*

Ernest Rutherford knew alpha particles (hydrogen nuclei) could expose photographic plates and could be beamed through very thin pieces of material to produce a fuzzy image. Two of his students conducted an experiment where alpha particles were beamed through a very thin piece of gold foil (about 0.00004 centimeter, which is only a few atoms thick) to determine what type of pattern the particles would form on the other side of the foil.

Rutherford noticed that most of the alpha particles went straight through the foil and were recorded by the detecting instrument directly behind the foil. But a detector off to the side at about 45 degrees also picked up some signals, indicating that something in the foil was deflecting a few of the alpha particles. Rutherford noticed that although most particles went through the foil as if nothing was there, a few were deflected to the side, and a few actually seemed to bounce backwards toward the source. He said, "It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper, and it came back to hit you." After making some calculations, he concluded that this backward scattering of the alpha particles is evidence of a few collisions with something where almost all the mass is concentrated in a central, very small "nucleus." It was at this point that he realized this central nucleus had a positive charge (*see* Figure R2).

See also Bohr; Curies; Mosely; Soddy

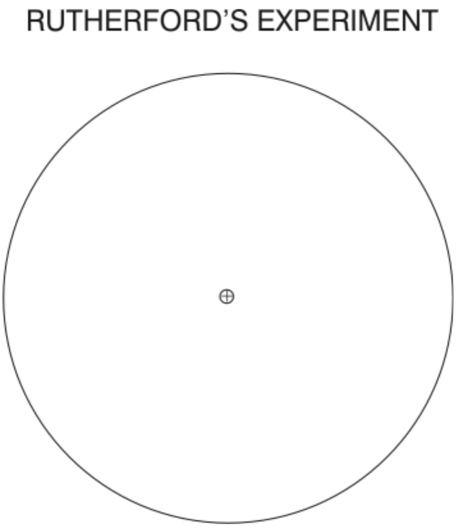

Figure R2. Rutherford's experiment indicated that the positively charged atom consisted almost entirely of a massive but very small positive nucleus. The atom consisted of a vast area around this tiny nucleus. Negatively charged electrons that weigh much less than the positively charged central nucleus occupy the outer reaches of this area. His conclusion was that the atom is mostly empty space.

RYDBERG'S THEORY OF PERIODICITY FOR ATOMIC STRUCTURE: Physics: *Johannes Robert Rydberg* (1854–1919), Sweden.

Elements can be organized by the structure of their atoms based on their spectra rather than according to their mass.

In the 1880s Johannes Rydberg was aware that Swiss mathematician and physicist Johann Jakob Balmer first discovered the relevance of the spectral lines of the hydrogen atom. Balmer found there was a simple relationship between the wavelength of the lines and the spaces between them when expressed on a graph. Rydberg's theory and experiments provided the explanation for this relationship. He examined the spectra of hydrogen atoms and discovered that the frequencies of the excited atoms produced a spectrum that can be stated as a constant, relating the wavelength to a series of lines in the spectrum. The Rydberg equation can be stated as: $\lambda = R(1/m^2 - 1/n^2)$, where λ is the wavelength, R is the Rydberg constant, and m and n are whole numbers squared. It can also be expressed as $1/\lambda\ R(1/1^2 - 1/m^2)$, where m must be an integer larger than 1. The Balmer spectra series for atoms represented only the shorter ultraviolet range. Rydberg proceeded to reorganize Dmitri Mendeleev's **Periodic Table of the Chemical Elements** according to the structure of atoms based on their spectral lines (*see* Figure M5 under Mendeleev). After applying his equations to the patterns of atomic structure, Rydberg developed a spiral form of the periodic table. Soon after Rydberg developed his equations, Henry Moseley determined that the nuclei of atoms had positive charges, which confirmed Rydberg's and Rutherford's theories.

See also Balmer; Bohr; Mendeleev; Moseley; Newlands; Rutherford

RYLE'S THEORY OF USING RADIO ASTRONOMY FOR OBSERVING DISTANT GALAXIES: Astronomy: *Martin Ryle* (1918–1984), England. Martin Ryle shared the 1974 Nobel Prize in Physics with Antony Hewish.

By using two smaller astronomical interferometer type radio telescopes located in a 1.5 kilometer diameter area, a synthesis of their apertures can be analyzed and thus improve the computation of data received from radio signals from distant quasi-stellar objects called "quasars."

Sir Martin Ryle earned a degree in physics from the University of Oxford in England in 1939. During World War II he helped design radar equipment that eventually helped save England from German air attacks. After the war, he became director of the Mullard Radio Astronomy Observatory, which is located at the University of Cambridge, and later a professor of radio astronomy. He was elected to the Royal Society in 1952, knighted in 1966, and later became the Astronomer Royal from 1972 to 1982.

Early in his career he led the effort of the Cambridge Radio Astronomy Group in their production of several radio astronomy catalogues that, in time, led to the discovery of the first quasar. His major achievement was the development of the theory that greater definition and depth could be achieved by connecting two smaller radio telescopes into one large one, thus enlarging the viewing aperture of the whole system. He led the construction of such a system. His technique is known as "aperture synthesis," which means by using two smaller telescopes on rails with adjustable positions within a 1.5 kilometer diameter area, he could obtain the same results as one huge radio telescope. While using this system, he discovered the location of the first pulsar. Later, his theory of aperture synthesis was expanded by constructing several smaller radio telescopes on rails in an area 5 kilometers in diameter. By adjusting the positions of the entire telescope system and synthesizing their individual signals, he was able to make observations crucial to the study of the physical characteristics of stars and systems of the cosmos. It also led to a better understanding of the universe as a whole. One example is the discovery of a unique type of distant signal that sent pulsating radio waves that were repeated on a very regular basis several seconds apart. His aperture-synthesis system of radio telescopes also established the presence of neutron stars that were predicted by astronomers for some time but not previously discovered. Neutron stars are relatively small—only about 10 kilometers in diameter. However, merely one cubic centimeter of its "stuff" is estimated to weigh millions of tons. It seems pulsars consist of matter similar to the neutron stars and have a magnetic field of great energy, stronger than any magnet ever produced in the laboratory. Both the pulsar stars and neutron stars are surrounded by gas-like plasma. When viewed from Earth, the quasar-neutron star appears as a radio beacon. The best-known pulsar star was first viewed by the Chinese in the eleventh century and is found in the Crab Nebula. It is a glowing gas cloud, the remains of a giant stellar explosion. At the center of the Crab Nebula is an expanding neutron star that sends several different frequencies of electromagnetic radiation, including light pulses, X-ray pulses, as well as the detected radio pulses.

See also Hewish

One of the great debates in the history of astronomy took place in the 1950s between two British astronomers, Sir Martin Ryle and Sir Fred Hoyle. It seems that Fred Hoyle came up with the term "big bang" as a pejorative term for those who believed in the cosmic theory of an expanding universe starting from a singularity point and rapidly expanding, and which is still expanding. Hoyle was a proponent of the steady-state universe, while Martin Ryle accepted the expanding universe theory. Their arguments became not only a scientific debate but also a personal feud. One thing this dispute did was awaken an interest in the two theories and spurred much more research into the origins of the universe, as well as cosmology in general. Recent research indicates that the big bang is not only the correct theory, but it is now assumed that it all began with one giant "explosion" of matter and energy.

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SABIN'S THEORY FOR ATTENUATED LIVE POLIO VACCINE: Biology: *Albert Bruce Sabin* (1906–1993), United States.

> *If live poliovirus can be grown in tissue cultures, it can be attenuated (weakened) and used to vaccinate humans against poliomyelitis (infantile paralysis).*

During World War II Albert Sabin developed vaccines for diseases such as dengue fever and encephalitis and was familiar with the work of other microbiologists who experimented with the growth of viruses in the brains of mice. In 1954 Jonas Salk (1914–1995) used poliovirus "killed" by formaldehyde, which was then injected to stimulate the human immune system, thus developing antibodies against the disease. Outbreaks of polio were common, particularly in the summer months. In 1952 and 1953 the United States alone had outbreaks of the disease with fifty-eight thousand and thirty-five thousand cases, respectively. Prior to this, the usual number of cases reported was around twenty thousand. Thus, immunization was not completely successful, and the vaccine had to be injected several times over a period of years. Also, the dead virus's effects on the immune system did not last a lifetime. Albert Sabin developed a live but weakened version of the poliovirus in the kidney tissue of monkeys. His version for providing immunity to the virus could be taken orally and had a lasting effect for producing antibodies as a preventative against the virus. The oral-attenuated virus is still being improved. After testing his attenuated live virus on animals, Sabin tested it on himself and several prisoners who volunteered to test its efficacy. The U.S. public was skeptical of Sabin's vaccine due to the problems experienced with the earlier Salk vaccine. Finally, after successful use in Russia and England, it was accepted in the early 1960s and extensively used in the United States as an oral vaccine that prevented the outbreak of polio epidemics. Currently, there are two types of polio vaccine available. One is called inactivated polio vaccine (IPV) that is administered via an inoculation with a sterile syringe. The other is called a live oral polio vaccine (OPV) that is a liquid that is swallowed. As of the year 2000 the United States uses the IPV form of the vaccine almost exclusively. (OPV is administered in special circumstances.) However, OPV is used in parts of the world where polio remains a threat to the population because it is more effective in preventing the spread of the disease. In rare cases, OPV can cause polio. IPV does not. The incidence of polio has drastically decreased. As recently as 1988, it was estimated that three hundred and fifty thousand people were stricken with the virus. According to the Center for Global Development, in 2006 only four countries were endemic for the poliovirus with less than seven hundred cases reported worldwide. The last outbreak of endemically transmitted poliovirus in the Unites States occurred in 1979 among the Amish population in several midwestern states.

See also Jenner; Pasteur

SACHS' THEORY OF PHOTOSYNTHESIS: Biology: *Julius von Sachs* (1832–1897), Germany.

> *Photosynthesis and starch formation occurs in the green pigment in plant cells which absorb energy from light and that are found in discrete bodies called chloroplasts.*

Over the centuries a number of scientists theorized about how plants grow, as well as the nature of the green material in their leaves. Aristotle believed that plants received all their food from soil. In the 1600s Johann Baptista Van Helmont conducted one of the first controlled experiments with plants. He planted a willow tree in a given amount of soil that he had carefully weighed. After five years of natural growth, he weighed the tree and the soil in which it was grown. The tree gained 160 pounds while the soil lost only a couple of ounces. He concluded that the willow tree gained not only its food but also its increase in mass from water. Until 1862 scientists believed the green material in plants was distributed more or less evenly throughout individual plants. Julius von Sachs was the first to theorize that the green matter was contained in small, discrete bodies he named *chromoplasts* (a colored cell, later given the name ***chloroplast***). He coated several leaves of a plant with wax and left others unwaxed. After exposure to sunlight, the unwaxed leaves produced starch, while the waxed leaves did not. Sachs concluded that the unwaxed leaves were able to absorb carbon dioxide, while the coated ones could not let this gas enter, even in sunlight. Thus, photosynthesis (from the Greek *photo*, which means "light," and *synthesis*, which means "put together") is the process whereby in the presence of light, chlorophyll in green plants converts carbon dioxide and water into starch: $6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2 \uparrow$ (the $\uparrow$ represents heat energy given off by the reaction).

See also Calvin; Cohn; Ingenhousz

SAGAN'S THEORIES OF NUCLEAR WINTER AND THE COSMOS: Astronomy: *Carl Edward Sagan* (1934–1996), United States.

Sagan's theory of nuclear winter: *A large-scale nuclear war can cause the ejection into the upper atmosphere of large amounts of smoke, ash, soot, and dust from burning cities and* *forests resulting in the blockage of sunlight and solar heat, the aftermath of which will be an extended period of winter on Earth.*

Scientists have known for many years that natural events, such as giant volcanic eruptions, great desert dust storms, and the collision of asteroids with Earth, can spew hundreds of millions of tons of particulate debris into the upper atmosphere, effectively blocking sunlight from reaching Earth's surface for months or years at a time. A massive blockage of sunlight would create extremely cold temperatures on Earth and greatly reduce plant growth resulting in the destruction of the supply of basic food for animals including humans. In the early 1980s a study called "TTAPS" (the initials stand for the names of the five researchers involved in the study: R. P. Turco, O. B. Toon, T. P Ackerman, J. B. Pollack, and more famously, Carl Sagan) developed a limited model based on a specific latitude plus a two-dimensional archetype of the atmosphere of the flat Earth. Other studies expanded their model to assume that at least half of the stockpiles of nuclear weapons of all nations would need to be used to destroy at least one thousand cities and most forests along with the production of tremendous amounts of fine dust in the atmosphere that would be opaque to solar radiation, resulting in the cooling of Earth's surface between 20° to 40°C for at least several weeks after the war. The results would be the opposite of global warming. In addition, much of the ozone layer would be destroyed, increasing the amount of ultraviolet radiation reaching Earth's surface by about 200%. A more recent 2006 study found that even a small-scale regional nuclear war could produce as many casualties as did World War II, and that global climate would be disrupted for many years. The study concluded that even a limited nuclear war could send millions of tons of soot into the stratosphere producing a cooling of several degrees over much of Earth, including the regions where most of the food plants are grown. As a continuum to his nuclear winter theory, in 1991 Carl Sagan predicted on ABC's *Nightline* TV program that the smoky oil fires resulting from the burning of the hundreds of oil wells in Kuwait during the Persian Gulf War could cause worldwide ecological disaster resulting in global cooling. The atmospheric scientist Fred Singer, also a guest on *Nightline* appearing with Sagan, was a skeptic and stated that Sagan's prediction was nonsense because the clouds from the burning oil wells would dissipate in a few days. Richard Feynman and Freeman Dyson, well-known scientists, are quoted as responding to Sagan's paper on nuclear winter as an "absolutely atrocious piece of science." Sagan later admitted in one of his books that his prediction related to the smoke from the burning oil wells was one of his mistakes. Since the days of "nuclear winter" and the end of the Cold War, the emphasis and interest of climate scientists, politicians, and the media has shifted to global warming.

Sagan's planetary and cosmos theories: *Life, either present or past, may have existed on other planets or satellites of planets (moons) in the solar system, or even beyond in deep space.*

Carl Sagan based many of his planetary theories on laboratory research experiments and data collected from artificial satellites that provided information concerning the various types of organic molecules that make up the atmospheres on Earth, as well as other planets. His main goal related to this research was to discover and understand the origins of life on Earth, as well as possible life elsewhere in the universe. He postulated that there are "billions and billions" of stars in billions of galaxies, and thus billions of these stars are of average size with planets orbiting them. He further estimated that at least one of these planets among the billions of stars is at an optimum distance

Carl Sagan was somewhat of an enigma in life and as a scientist. From early childhood he marveled at the stars and the vastness of the universe. He followed this interest for the rest of his life. After attending several universities and being involved with NASA's early space program, his interests expanded to include concepts of religion and scientific beliefs, origins of life, other life in the universe, and democratic humanism. He became a national spokesperson for the wonders of the universe as he wrote several well-known books, as well as a prominent TV commentator and speaker at many conferences. Although accused of being an atheist, he insisted that an atheist is someone who is certain that God does not exist and has proven evidence for that belief. He said that he had no evidence that a god does not exist and that people with open questioning minds should challenge dogmatic claims about all aspects of the ultimate reality, both scientific and religious. He refuted "postmodernism" claims that 1) scientists idolize science and 2) that the scientific method destroys the philosophies that ponder the mysteries of nature and religious beliefs. He claimed that science is not a form of idolatry but that the scientific method is a way that humans can distinguish the false idols from reality and is the "best" method yet devised for humans to use as a way of life. He also believed that neither scientists nor theologians have all the answers and comprehend the vastness of the universe. Sagan gently chided traditional religions for persisting in their assertions about the natural world and cosmos that were contradicted by answers to questions of nature. He distinguished between mysticism (magic and the occult) and spirituality, which he believed is compatible with science—science itself is a source of spirituality. Not all scientists agreed with this last statement, but, Sagan, although a skeptic, was a great humanist who believed that science was a source of spirituality. He deplored scientific illiteracy and advocated that skepticism should be integrated into early education programs. Carl Sagan was a great popularizer of science who died much too young at the age of sixty-two.

from their sun and has similar chemical and physical conditions that could amicably create and support life akin to Earth's life forms. Early in 2007 NASA announced the discovery of a new planet they named Gliese 581 c that is about five times heavier than Earth and is about 1½ times larger in diameter. It is revolving around a Red Dwarf Star. The planet has a temperature ranging from 34°F to 124°F, which is not too hot for life (temperatures on Earth have ranged from −131°F to 136°F). There is still much unknown about this new planet as there is unknown about the other 220 planets so far discovered outside our solar system.

During his time as a graduate student at the University of Chicago, Carl Sagan studied astrophysics and became interested in the atmospheres of planets. His 1960 PhD thesis proposed that the planet Venus in its past had undergone some drastic physical change that caused a massive greenhouse effect that was still evident on the planet. He was invited to join the team working on the first NASA satellite expedition to Venus in 1962 called *Mariner II*. The signals sent back to Earth from this satellite gave proof to Sagan's speculations concerning the greenhouse nature of the atmosphere of Venus. In the 1970s his research interest was the physical and chemical aspects of the solar system's planets, particularly the planet Mars. During his time as an adviser to NASA, Sagan and his colleagues, the exobiologist Cyril Ponnamperuna and NASA lab technician Ruth Mariner, demonstrated that particular organic molecules, including amino acids that are required to build proteins, could be produced by the energy of ultraviolet light. Included among these amino acids was adenosine triphosphate (ATP) that is a universal source of energy that would be needed for the origin of life. (Note: Exobiology is branch of biology that studies and searches for extraterrestrial living organisms.)

See also Miller; Ponnamperuma; Urey

SAHA'S THEORY OF THERMAL IONIZATION: Astronomy: *Meghnad N. Saha* (1894–1956), India.

The composition of a star's spectrum varies with the temperature of the light source.

Meghnad Saha theorized that the degree of ionization (electrons stripped from atoms to form ions) was dependent on the temperature of the atoms. He applied his concept to the spectrum of the light from stars. It was known that the light spectrum from some stars pointed to the presence of only hydrogen or helium, the two lightest elements. His examination of the spectra of stars indicated there were heavier elements (metals) that were being ionized in some stars. He developed a system that suggested the degree of ionization, and thus the stars' temperatures could represent spectral lines of stars. In other words, as the temperatures of stars increase, so does the degree of the ionization of the nuclei of the stars' atoms. Thus, atoms that have two or three ionization states will absorb sunlight at different wavelengths that produce different stellar spectra, whereas each light spectrum becomes stronger according to their proportions of the atoms' ionization increases. Saha's theory led to the linking of gas thermodynamics (heat) with the kinetics (molecular motion) of plasmas, which aided in interpreting the spectral lines of stars. His theory also enabled astronomers to determine the chemical makeup of different stars and confirmed the idea that heavy elements originated in stars, including the sun's gases.

See also Sakharov; Teller; Ulam

SAKHAROV'S NUCLEAR FUSION THEORY: Physics: *Andrei Dmitriyevich Sakharov* (1921–1989), Russia. Andrei Sakharov was awarded the 1975 Nobel Peace Prize.

Controlled nuclear fusion can be achieved by containing the plasma in a magnetic "bottle."

Andrei Sakharov's theory described how by confining a deuterium plasma (a highly ionized gas) within a strong magnetic field, the temperature could be raised to the point where the heavy hydrogen (deuterium) gas molecules would be forced to fuse to form helium molecules. The resulting reaction would release a tremendous amount of energy that could be used to produce electricity, much like the controlled nuclear fission reaction in nuclear power plants. In the early 1940s the United States developed the first nuclear fission bombs. In 1954 Sakharov was involved in the explosion of Russia's first atomic (**fission**) bomb, as well as its first nuclear (**fusion**) H-bomb. After realizing the tremendous destruction that would result from a nuclear war, Sakharov became an advocate for nuclear disarmament, which led to his demotion and exile, and eventually the Nobel Peace Prize.

See also Teller

SALAM'S THEORY FOR THE PROPERTIES OF ELEMENTARY PARTICLES: Physics: *Abdus Salam* (1926–1996), Pakistan. Abdus Salam shared the 1979 Nobel Prize for Physics with Sheldon Glashow and Steven Weinberg.

At very high temperatures both the electromagnetic and weak interacting forces act as a single interacting force for elementary particles.

Four basic forces account for the interactions of elementary particles: 1) electromagnetic forces and 2) gravity are observed to interact over long distances throughout the universe. The electromagnetic force both attracts and repels, thus counteracting its strength. Gravity is a very weak force that only attracts and never repels (at least there is no known *negative* gravity force). Even so, it is the most dominant force in the universe. 3) The strong force interacts with hadrons (nuclei of atoms), while the 4) weak interacting force, which is much less strong, interacts with leptons (similar to electrons and neutrinos). The forces that interact with hadrons and leptons are evident only at the very small atomic and subnuclear distances of matter (*see* Figure G11 under Glashow for a chart of the Standard Model for the unification of the particles of physics). Albert Einstein attempted to devise a mathematical solution to combine the electromagnetic and gravity interacting forces. He was unsuccessful, and at that time, the other two interactions with elementary particles were unknown. In 1968 Abdus Salam and his colleagues successfully combined the electromagnetic and weak forces, which behaved as a single interacting force, but only at high temperatures.

The analogy used is that at high temperatures, water turns into steam. As the temperature drops, it again becomes liquid, and if it drops further, it becomes solid (ice). In other words, for electromagnetic and weak interactions, there are two different physical states of being, depending on the temperatures involved (combined at high temperatures and separate at low temperatures). Abdus Salam and the other Nobel Prize winners referred to the high-temperature combined state as the electroweak interaction. Salam's theory is a great step in the development of a grand unification theory (GUT) and Einstein's unified field theory.

See also Einstein; Glashow; Weinberg

SANDAGE'S THEORIES OF QUASARS AND THE AGE OF THE UNIVERSE: Astronomy: *Allan Rex Sandage* (1926–), United States.

Sandage's theory of quasars: *Quasars can be identified by their emitted radio signals, ultraviolet radiation, and blue light.*

In the early 1960s Allan Sandage detected radio signals from a small area in the distant universe. These radio signals seemed too strong to be originating from such a distant dim star. He and other astronomers referred to these objects that produced ultraviolet and blue light radiation as blue star objects (BSOs). Sandage determined they were not really radio stars. Therefore, he called them quasi-stellar or *star-like* bodies (*quasi* means "apparently" and *stellar* means "star"). This term was changed to *quasar* and used ever since. Sandage realized these objects exhibited a great Doppler redshift, which overcame the ultraviolet and blue light. He concluded this could only mean that the quasars were located at tremendous distances within the universe and that what could be seen from Earth was really the center of a huge galaxy. Later Allan Sandage and his team estimated the distance of such quasar galaxies to be over 12 billion light-years away. The first quasar that Sandage discovered was named 3C 48, which had the brightness of a sixteenth-magnitude star (*see* Pogson).

Sandage's theory for the age of the universe: *The universe has an eighty-billion-year cycle of growth: forty billion years of expansion and forty billion years of contraction.*

Allan Sandage does not believe the universe is static, regenerating itself, or expanding indefinitely. His contention is that the universe oscillates in cycles of expansion (birth and growth) and contraction (shrinking, death, and followed by rebirth). His theory states that after a forty-billion-year period of expansion (it still has about twenty-five billion years left to reach maximum growth because the current universe is about thirteen or fourteen billion years old), the universe will cease to expand, reverse itself, and start contracting for another forty billion years of the cycle. At the end of this contraction period, he contends it will form back into its original, tiny, very dense "point" particle for a new singularity that will again create another big bang that will start the process all over again. It might be mentioned that not all cosmologists agree with Sandage's theory, which is just one of many dealing with the dynamic nature and age of the universe and is partly based on the estimation of the density of matter in the universe, which has yet to be accurately determined. More recently, it has been estimated that the vast majority of matter and energy in the universe is **dark matter** and dark energy that cannot be seen but implies an infinite universe.

See also Einstein, Glashow; Rubin; Schmidt; Weinberg

SANGER'S THEORIES OF THE STRUCTURE OF PROTEINS AND GENE SPLITTING: Chemistry: *Frederick Sanger* (1918–), England. Frederick Sanger was one of the few people to be awarded two Nobel Prizes. The first one in Chemistry in 1958 for determining the structure of proteins, and the second prize, also in chemistry, that he shared with Paul Berg and Walter Gilbert, in 1980 for determining the base sequences of nucleic acids.

Sanger's theory of protein structure: *The four amino acids that make up proteins connect in groupings and can be identified in sequences inside the protein molecule.*

Frederick Sanger used the process called paper **chromatography** to separate and count the number of amino acids in specific protein molecules. Once these groupings were broken into segments of two, three, or four amino acids, he determined the structure of large and complete protein molecules. In 1953 he used this procedure to outline the complete structure of the molecule for the protein hormone insulin. It consists of fifty amino acids combined in two connecting chains. Since his identification of the exact order of the amino acid groups in the chains, it became possible for other scientists to produce synthetic insulin, used in the treatment of diabetes.

Sanger's theory of gene splitting: *DNA can be split into fragments of various sizes, isolating a few cases of genes within genes.*

Frederick Sanger developed a new technique of splitting DNA into fragments to determine the base sequences of the nucleotides. In 1977 he was the first to describe the entire sequence of nucleotides in the DNA of a bacteriophage (a virus that infects a bacteria cell, also called **phage**) called Phi-X 174. To accomplish this, he needed to ascertain the order of about fifty-five hundred nucleotides in just one strand of the phage's DNA. While examining his results, he unexpectedly discovered several situations where genes were located within other genes. Today this phenomenon is used to explain traits of genetic expression. Sanger's theory and research contributed to the foundations for the science of genetic engineering.

See also Sharp

SARICH'S THEORY OF UTILIZING PROTEIN TO GENETICALLY DATE MAN/APE DIVERGENCE: Biology: *Vincent Sarich* (1934–), United States.

When species split into two branches, future mutations for each branch are accumulated in a linear manner, and the greater the number of mutations, the greater the time divergence.

Vincent Sarich used the albumin found in blood protein as a determinant for the divergence of humans and apes from a common ancestor. The concept is based on the facts that there is only about 1% difference between humans and apes in the DNA protein molecules and that mutations of individual genes not only differ for individual genes but also mutate on a random basis at a measurable rate over time. Thus, it should be possible to determine the rate of changes in the albumin of humans and apes over a long time span. He called this technique the *molecular clock*. Sarich and his colleague Allan Wilson began with the base of thirty million years ago as the estimated time the species of humans and Old World apes evolved separately from a common ancestor (the "missing link"). After analyzing the data that compared antigens from humans and other anthropoids, which have a common genetic base, they proposed a time factor of about five to seven million years ago when the two species evolved in their own directions. Other scientists disputed this short time period and claimed that fossil evidence places the division of **hominoids** and **hominids** from a common ancestor at about fifteen million years. Sarich responded that his molecular data were more accurate than the estimations of the age of the oldest human fossils. The accuracy of his work led to agreement for his five-million-year figure and is now accepted, as recently as 2006. Also there is now some evidence suggesting that chimpanzees are more genetically similar to humans (over 98% of the same DNA) than they are to gorillas and that chimps and humans should be classed in the same genetic family.

See also Wilson (Allan)

SCHEELE'S THEORY OF THE CHEMICAL COMPOSITION OF AIR: Chemistry: *Karl Wilhelm Scheele* (1742–1786), Sweden.

Air is composed of two gases, one of which supports combustion, while the other does not.

One of the gases that Karl Scheele isolated in air he named *fire air* (oxygen) because it supported combustion. The other, which prevented combustion, he named *vitiated air* (nitrogen). In 1772, about two years before Joseph Priestley produced oxygen (which Lavoisier named), Scheele actually isolated oxygen and described it in a paper. However, his findings were not published until after Priestley's discovery of the same gas. Priestley published his discovery first, thus he was given the credit.

See also Lavoisier; Priestley

SCHIAPARELLI'S THEORY OF REGULARITY IN THE SOLAR SYSTEM: Astronomy: *Giovanni Virginio Schiaparelli* (1835–1910), Italy.

Meteors, planets, and the rings of Saturn follow regular patterns within the solar system.

In 1877 the planet Mars was in conjunction with Earth—only about 35 million miles away. This proximity provided Giovanni Schiaparelli and other astronomers an opportunity to view Mars' surface for details. Despite the fact the atmospheres of Earth and Mars hindered a clear view, others confirmed Schiaparelli's record of his observations. He reported narrow and larger dark markings on the surface of Mars, which he concluded were bodies of water connected by narrow "channels" he called *canali*. He claimed these markings represented geometric patterns, which indicated some degree of regularity. It was speculated these patterns were the result of "constructions" by Martians. Others later expanded his concepts of regular structures to propose that Mars was a dying planet and these channels were the work of a desperate race attempting to bring water from the Martian ice caps to the tropical areas, where it could be used to grow plants. Myths about life on Mars existed for many decades until modern exploratory spacecrafts were sent to Mars to examine its atmosphere and surface.

Another example of Schiaparelli's theory of regularity is his claim that some natural physical process formed the rings of Saturn. Another is that meteor showers are caused by the breakup of comets. Thus, meteors must follow regular orbits similar to comets. One of his major theories of regularity states that the rotations of Venus and Mercury on their axes are synchronized with their sidereal periods. Therefore, these two planets always keep their same side facing Earth. He based this concept on his viewing of the same markings on these planets' surfaces when they were in a specific position. In the 1960s Schiaparelli's theory that these two planets keep their same side facing the sun was disproved when radar signals bouncing off their surfaces indicated that Venus rotates on its axis every 243 days, while its sidereal period is 225 days; Mercury rotates on its axis about once every 59 days, while its sidereal period is 88 days.

See also Cassini; Huygens; Lowell; Roche

SCHLEIDEN'S CELL THEORY FOR PLANTS: Biology: *Matthias Jakob Schleiden* (1804–1881), Germany.

Plant structures are composed of small, distinct "walled" units known as "cells."

In 1838 Matthias Schleiden first recognized and reported on the "cellular" basis of plants, which he referred to as "units" of plant life. (Note: Robert Hooke was the first to use the term "cell" for the minute structures he observed in a slice of cork. Using his compound microscope, the gaps in the cork's texture reminded him of the tiny monks' rooms in monasteries that were called *cells*.) Schleiden was first to note the importance of the nuclei in the reproduction of plant cells. He mistakenly thought that cells reproduced by the "budding" of new cells from the "mother" cell's nuclei. After Schleiden's discovery of plant cells, Theodor Schwann, also in about 1838, announced that animal tissues were also composed of cells, but with much less well defined cell walls. This led to the biological concept that cells are a basic unit of all living organic things. From this fundamental idea and the research of several other biologists, Schleiden and Schwann have been credited with the formulation of the cell theory, which states:

- All plants and animals are composed of cells or substances derived from cells.
- Cells are living matter, with membrane walls and internal components.

- All living cells originate from other cells; cells reproduce themselves.
- For multicellular organisms, the individual cells are subordinate to the whole organism.

Some of Schleiden's and Schwann's original observations and ideas were incorrect due to the very limited power of the microscopes available to them. But over time and with additional research by others, their concept that cells are the basic units of life became an important step in understanding living organisms.

See also Hooke; Leeuwenhoek; Schwann; Strasburger; Virchow

SCHMIDT'S THEORY OF THE EVOLUTION AND DISTRIBUTION OF QUASARS: Astronomy: *Maarten Schmidt* (1929–), United States.

> *Quasars exhibit a greater red shift than regular stars. Therefore, they are younger, more distant, and more abundant stellar-like objects than stars.*

Maarten Schmidt expanded his research of our Milky Way galaxy to include the very dim and distant objects discovered in 1960 by Allan Sandage and Thomas Matthews. Sandage called these objects *quasars*, meaning "starlike." The first quasar, designated 3C 48, was identified by the radio signals that it emitted. Schmidt studied its light spectrum. Even though it had the luminosity of only a sixteenth-magnitude star (*see* Pogson), he found it exhibited the spectral lines of the element hydrogen. When viewing other quasars, their spectra became more confusing, until Schmidt realized that the hydrogen spectra lines shifted in wavelengths toward the red end of the spectrum. This Doppler red shift of light, which was greater than expected from a star, indicated that quasars are emitting great amounts of energy and light as they recede from Earth at fantastic velocities. The greater the red shift, the greater the speed at which they recede. Schmidt examined the hydrogen lines whose wavelengths had shifted to the red end of the spectrum, indicating that another quasar, named 3C 273 was receding as the universe continued to expand after the big bang. The extreme red shift could mean only that quasar 3C 273 was not only at least one billion light-years away, but its brightness was that of hundreds, or possibly thousands, of galaxies in a cluster. Schmidt's theory asserts that quasars are among some of the earliest types of matter formed when the universe was young, and because they continually recede from us (and each other), they become more abundant as the universe ages. Schmidt proceeded to map the quasars in the universe, leading him to conclude that the so-called steady-state universe cannot exist. He and others interpreted their red shift data as indicating that the number of quasars increases with distance and that no objects have been located at greater distances. The possible demise of the steady-state universe concept has generated theories about an infinite universe. More recently, the discovery of **black holes** has advanced the theory that these huge dark masses of matter, from which matter or light cannot escape, are the source of the tremendous energy of quasars, or possibly the source of new quasars or even new universes.

See also Doppler; Gold; Hawking; Hubble; Sandage; Schwarzschild

SCHNEIDER'S THEORY OF BIOLOGICAL SYSTEMS AND CLIMATE CHANGE: Meterorology: *Stephen Henry Schneider* (1945–), United States.

> *Coupled with the fields of physical and biological scientific research, as well as social and political assessments, global climate studies can identify the factors, risks, consequences, and possible solutions associated with the phenomenon known as ''global warming.''*

Stephen Schneider is a climatologist who is currently on the faculty of Stanford University in California as a professor of environmental biology and global change. He is concerned with the interdisciplinary aspects that combine the sciences of physics and biology, along with social/public interests, related to global climate changes. In other words, the object is to combine the disparate factors and uncertainties and all the political assessments into a cohesive method to address the risks and benefits of global climate change, commonly referred to as global warming.

Schneider was the leader of a team at the National Center for Atmosphere Research at Boulder, Colorado, involved in the construction of a mathematical-based computer model that related a grid-like pattern of the world's climates at the surface of Earth. This imaginary grid consisted of about two thousand boxes of atmosphere, all connected together at about 30 kilometers in altitude (just think of the total atmosphere divided into two thousand partitions or boxes that surround Earth). Factors, such as temperatures and pressures in each box, were analyzed using the largest computer available in the late 1980s. This mathematical computer model could predict *weather* in broad cyclic categories and patterns of specific boxes, but not for the entire climate of the entire globe. It could determine *regional* future cooling in winter and warming patterns in summer. Benefactors who provided billions of dollars to fund this research wondered why the model only predicted what any grammar school student knew from the few years of experiencing temperature changes from summer to winter. Furthermore, this model could not predict accurately the climate change, if any, for a specific region. Since that time, computers have become much more technically advanced and the mathematical models more sophisticated to the extent that they can include more unknown variables in the models and provide improved output predictions. Unfortunately, there are still many factors that are not included in even the best computer climate models. For example, are all the factors that are involved in the continual evolution of our dynamic Earth incorporated in the model? Is the changing nature of the interior of Earth involved, and if so how? How do we account for several past global warming and cooling periods? And how and why did past global warming periods end? There are thousands of variables involved, but we do know that there are several gases (carbon dioxide, methane, nitrous oxide, sulfur dioxide, water, etc.) that nature and humans put into the atmosphere that affect *radiation forcing* which is defined as the change in the balance between radiation entering and escaping Earth's atmospheric system. A variety of research techniques are used to provide input for the study of global warming, such as the analysis of ice cores, deep ocean studies, and population studies. And yes, people, as do all animals and other living organisms contribute to the global climate change problems. The mathematical computer model capable of predicting long-term linear projections for future worldwide climates has yet to be constructed.

Schneider is a firm believer that the three main components of the climate change scenario (climate science, climate impacts, and climate policy) should be a major concern of all three parties in the triangle of "journalist-scientist-citizen." Before consensus is reached, all groups should insist that the most up-to-date scientific assessments of climate studies and global warming are incorporated into media reports that are disseminated to a concerned population. In other words, the natural and dynamic processes of Earth that have controlled cataclysmic climate changes long before human civilization must be factored into the current climate models that focus on manmade pollutants that may be hastening an otherwise inevitable shift.

SCHRÖDINGER'S THEORY OF WAVE MECHANICS: Physics: *Erwin Schrödinger* (1887–1961), Austria. Erwin Schrödinger shared the 1933 Nobel Prize for Physics with Paul Dirac.

An electron's position in an atom can be mathematically described by a wave function.

In 1925 the quantum theory was developed through efforts of Erwin Schrödinger, Niels Bohr, Werner Heisenberg, and others. Schrödinger was aware of Niels Bohr's application of the quantum theory to describe the nature of electrons orbiting the nuclei of atoms and Louis de Broglie's equation describing the wavelength nature of particles ($\lambda = \hbar/mv$, where λ is the wavelength, $\hbar$ is Planck's constant, and mv is the particle's momentum, i.e., mass times velocity). Schrödinger thought de Broglie's equation, which applied to only a single electron orbiting the hydrogen nuclei, was too simplistic to describe the state and nature of the electrons in the inner orbits of more complex atoms. Schrödinger laid the foundation of wave mechanics as an approach to quantum theory, resulting in his famous complex wave differential equation, a mathematical nonrelativistic explanation of quantum mechanics characterized by wave functions. Quantum theory is based on two postulates 1) energy is not continuous but exists in discrete bundles called "quanta" (e.g., the photon is an example of a discrete bundle of

> Possibly the most famous cat in the history of physics was "Schrödinger's cat." He used this "cat" as a thought experiment to illustrate the incompleteness of quantum mechanics when physicists proceed in their thinking from microscopic subatomic systems to larger macroscopic systems. The cat thought experiment that grew out of a discussion between Albert Einstein and Erwin Schrödinger is a good example of the probabilistic outcomes in nature. The "experiment" depends on establishing a system where there is exactly a 50-50 chance of an occurrence of a particular quantum event, such as the decay of a radioactive nucleus of an atom. In essence, the experiment involved a cat that is enclosed in a small room or a box isolated from the outside environment. Enclosed with the cat are a Geiger counter, a small bit of radioactive material, and a bottle of poison gas. There is no given time, rate, or sequence at which the radioactive nuclei of atoms in the material will disintegrate. When will the Geiger counter that has been set to do so, in turn, release the poison gas that kills the cat and thus detect a single bit of energy radiating from a single nucleus? The question is: What is the *probability* that this sequence will occur in just one hour? Schrödinger stated that if the cat is truly isolated from external interference, then the state of the radioactive material, the Geiger counter, and the cat being either alive or dead are in a superposition of states. Each of these three states are 1) the radioactive material has either decayed or not decayed, 2) the poison gas has either been released or it has not, and 3) the cat has or has not been killed. The observer interfering with the experiment by making measurements can only determine the true states of these three positions. In other words, the observer becomes entangled with the experiment. Thus, subatomic particles can only exist in probabilistic states and the concepts related to quantum mechanics cannot be scaled up to large macro systems—such as cats.

light energy) and 2) subatomic particles have both wave (frequency) and particle-like (momentum) characteristics. His equation proved more useful in describing the quantum energy states of electrons in terms of wave functions than Bohr's quantum mechanical theory of particles orbiting around the nuclei of atoms. The wave function can be determined by the solution of a differential equation that has been named after Schrödinger. Schrödinger's theory for the wave nature of particles advanced the acceptance of the wave-particle duality of quantum mechanics.

See also Bohr; de Broglie; Dirac; Heisenberg; Nambu

SCHWANN'S THEORY OF ANIMAL CELLS: Biology: *Theodor Schwann* (1810–1882), Germany.

The formation of cells is a universal principle for living organisms.

In 1838 Mathias Schleiden proposed a cellular theory for plant tissues. At about the same time, Theodor Schwann made microscopic examinations of various animal tissues. He had already formulated the concept that animal tissues, particularly muscle tissues, were mechanistic rather than vitalistic (life based on some other agent than matter and energy). Schwann suggested the substances that compose animal tissues do not evolve directly from molecules but rather from cells, and the material contained in animal "cells" is similar to plant cells. He stated that just as plant cells are derived from other plant cells, so are animal cells derived from other animal cells. However, Schwann mistakenly assumed that the material inside cells did not have any structure of its own except for what he called a "primordial blastema." Schwann's theory stated that animal cells represented fundamental units of life. Although he did not believe in spontaneous generation, he at first claimed that cells arose from nonliving matter. This proved to be a paradox until it was determined that all cells originate from other cells. Schleiden and Schwann are both credited for developing the cell theory that states all organisms are composed of cells, which are the basic structural and functional units of life. *See* Schleiden for details of the cell theory.

See also Hooke; Virchow

SCHWARZSCHILD'S "BLACK HOLE" THEORY: Astronomy: *Karl Schwarzschild* (1873–1916), Germany.

Once a star collapses below a specific radius, its gravity becomes so great that not even light can escape from the collapsed star's surface, thus resulting in a black hole.

Karl Schwarzschild was an astronomer who, in addition to providing information about the curvature of space and orbital mechanics, studied the surface of the sun. His theoretical research indicated that when a star is reduced in size to what is now called the *Schwarzschild radius* (SR), its gravity becomes infinite. In other words, if a star with a specific mass is reduced in size to the critical Schwarzschild radius, its gravity becomes so great that anything entering its gravitational field will not escape. The edge of the **black hole**, which is referred to as its *horizon*, is the zone where the escape velocity from the hole exceeds the speed of light. The critical spherical surface region of a black hole where all mass and light are captured is called the *event horizon*. Schwarzschild used the sun to determine this critical radius for stars. The SR for the sun, when it does collapse, will be about 3 kilometers, and it will be incredibly dense. (Because the sun's current radius is about 700,000 km, it will be many billions of years before it "shrinks" to the SR of 3 km.) To determine the SR for other stars, divide the object's (star) mass by the mass of the sun and multiply by 3 km. This equation might be expressed as: $M_o \div M_s \times 3$ km $= M_o$'s SR (M_o is the mass of the object for which SR is to be determined, M_s is the mass of the sun). Therefore, the critical radius for a black hole is proportional to its mass. The current theory suggests that a black hole may be open at the bottom of its "funnel shape," where the mass that was captured by the black hole may reemerge as new stars or a new universe. Although the concept of black holes is demonstrated by mathematics, the idea that the "lost" mass will exit or escape to form another universe has not been proven.

See also Hawking; Penrose

SCHWINGER'S THEORY FOR RENORMALIZATION: Physics: *Julian Seymour Schwinger* (1918–1994), United States. Julian Schwinger shared the 1965 Nobel Prize for Physics with Richard Feynman and Sin-Itiro Tomonaga.

> *Electromagnetic theory and quantum mechanics can be combined into a science of "quantum electrodynamics."*

Julian Schwinger was somewhat of a child prodigy who attended the public schools of New York City and entered the City College of New York at the age of fourteen where he published his first scientific paper at age sixteen. After transferring to Columbia University, he received his BA in 1936 and his PhD in 1939. He then worked with Robert Oppenheimer at the University of California before moving to Purdue University in Indiana. During World War II he worked in the Radiation Laboratory at Massachusetts Institute of Technology (MIT) where he was sent to work on the atomic bomb at the University of Chicago. He so disliked working on the bomb project that he just drove back to MIT to work on radar. After the war, he accepted a professorship at Harvard University from 1945 to 1974. It was during his tenure at Harvard that he devised his first concepts of renormalization related to quantum electrodynamics while he continued his study of particle physics.

Several other scientists, including Paul Dirac, Werner Heisenberg, Wolfgang Pauli, and later Richard Feynman, Sin-Itiro Tomonaga, and Freeman Dyson, laid the groundwork for the theory of quantum electrodynamics (known as QED). They contributed to the understanding of the behavior of how atoms and atomic particles react in electromagnetic fields, whereas Schwinger's contribution was the combining of electromagnetic theory and the field of quantum mechanics into the new field of quantum electrodynamics in a way that was consistent with Einstein's theory of relativity. This is a good example of how modern scientists, and in particular physicists, build on past theories and the accomplishments of others.

See also Dirac; Dyson; Edison; Feynman; Heisenberg; Weinberg

SEABORG'S HYPOTHESIS FOR TRANSURANIUM ELEMENTS: Chemistry: *Glenn Theodore Seaborg* (1912–1999), United States. Glenn Seaborg shared the 1951 Nobel Prize for Chemistry with Edwin McMillan.

> *The elements beyond uranium, atomic number 92, are similar in chemical and physical characteristics.*

In 1940 Glenn Seaborg and his colleagues discovered the first two elements beyond uranium (92). They are neptunium (93), a beta-decay element somewhat similar to uranium, and plutonium (94), a radioactive fissionable element used for nuclear reactors and bombs. The discovery of these new elements resulted in Seaborg's hypothesis that elements beyond uranium (92) formed a group of elements with similar characteristics that represented a new and unique series of elements. He compared this new series, named the *actinide transition series*, to the lanthanide series of rare earths, lanthanum (57) to lutetium (71), which also have very unique and similar characteristics. Seaborg used his hypothesis to predict the existence of many more "heavy" elements in his proposed *transuranic actinide series*. Still later in his career, he speculated there was a "superactinide" series of elements ranging in atomic number from about 119 to as high as 168 or even 184. All of these super-heavy elements, if discovered, will be radioactive, very short lived, and difficult to detect. In 1944, Seaborg and his colleagues discovered three new elements that are included in the **Periodic Table of the Chemical Elements**: plutonium (94), americium (95), and curium (96). Still later, Seaborg is credited with discovering berkelium (97), californium (98), mendelevium (101), nobelium (102), and lawrencium (103). The elements einsteinium (99) and fermium (100) were discovered after the detonation of the 1952 Hydrogen bomb and are artificially produced in nuclear reactors. Element 106, discovered in 1974, is currently named seaborgium (Sg), in honor of Glenn Seaborg. In 1999 Seaborg's Berkeley, California, laboratory announced the discovery of element 118, which has a half-life of about 0.00005 of a second. However, for years after its discovery, it has been mired in controversy amidst accusations of scientific misconduct.

See also Bohr; Fermi; Heisenberg; Lawrence

SEEBECK'S THEORY OF THERMOELECTRICITY: Physics: *Thomas Johann Seebeck* (1770–1831), Germany.

> *If electricity can produce heat when flowing through a wire, then a reverse effect should be possible; that is, heating a circuit of metal conductors should produce electricity.*

Thomas Seebeck was familiar with Joule's law, which in essence states: that a conductor (wire) carrying an electric current generates heat at a rate proportional to the product of the resistance (*R*) of the conductor (to the flow of electric current) and the square of the amount of current (*I* or *A*), (the current amperage). Using this information as a basis, in 1820 Seebeck joined the ends of two different types of metals to form a loop or circuit. When a temperature differential was maintained between the two different metal junctions, an electric force (voltage) proportional to the temperature differences between the two metal junctions was produced. This phenomenon is known as the *Seebeck effect*, where electricity is produced by temperature differences in the circuit. This device is now referred to as a *thermocouple*. If several thermocouples consisting of junctions between two dissimilar metals are connected in a series, a "thermopile" is formed, which can increase the voltage output equal to the number of junctions. It was later discovered that when the temperature of a single junction increases, the temperature decreases conversely at a second junction in the same circuit—the heat is transferred from one junction to the other. The rate of transfer is proportional to the current, and if the direction of the current is reversed, so is the heat (it is absorbed). In 1854 Lord Kelvin demonstrated that if there is a temperature difference between any two points on a conductor carrying a current, heat will be either generated or absorbed, depending on the nature of the material. It was later discovered that magnetism also affects this process. This principle has been applied to generate small amounts of electricity, as a "thermometer" to measure temperatures, and as a means of heating or cooling. Small heating and cooling devices in manned spacecrafts and portable refrigerators use the Seebeck effect.

See also Joule

SEGRÈ'S HYPOTHESIS FOR THE ANTIPROTON: Physics: *Emilio Gino Segrè* (1905–1989), United States. Emilio Segrè shared the 1959 Nobel Prize for Physics with Owen Chamberlain.

> *If anti-electrons (positrons) exist and can be produced in particle accelerators, antiprotons should also exist.*

In 1932, Carl Anderson built on Paul Dirac's idea that antiparticles are similar to elementary particles except for their electrical charges. The existence of the positron (positive electron) established the existence of the antiparticle positron, which unlike the negative electrons, has a positive charge but is similar to the electron in all other characteristics. Emilio Segrè, along with Owen Chamberlain, hypothesized that if antiparticles, such as positrons, can be generated in particle accelerators, antiprotons will also be generated if the accelerator is powerful enough. In 1955 they used the Berkeley Bevatron accelerator to generate six billion electron volts (BeV) to bombard copper with high-energy protons, which produced only one antiproton for about forty-thousand or fifty-thousand other kinds of particles. They detected these few high-speed antiprotons by the unique radiation they emitted, which was later confirmed by exposing photographic plates to **antiproton** tracks. At the time antiparticles were discovered, it was also theorized these antiparticles annihilated regular particles when they met—for example: $e^- + e^+ \rightarrow$ energy. The question was: Why isn't all the matter in the universe that is composed of elementary particles obliterated into energy if their antiparticles annihilate them? The answer is: At the time the universe was "created," more regular particles (e.g., electrons with negative charges) were formed than antiparticles (e.g., positrons with positive charges); thus the negative electrons now dominate.

See also Anderson (Carl); Dirac

SHAPLEY'S THEORY OF GLOBULAR CLUSTERS: Astronomy: *Harlow Shapley* (1885–1972), United States.

> *Masses of stars that are clustered together and known as "globular clusters" are found within the Milky Way galaxy.*

In 1920 a "great debate" took place between two famous American astronomers, Harlow Shapley and Heber D. Curtis (1872–1942) concerning the extent of the universe and the interpretation of galaxies. Harlow Shapley took two positions: 1) first, the sun was not at the center of the Milky Way galaxy and 2) that globular clusters and spiral nebulae are found within the Milky Way. Shapley's model of the galaxy moved the sun from the center to an outer location in a spiral arm. So he won on the first point of the debate, and his model for the location of the sun is still used today. On the second point Curtis believed that galaxies were not only smaller than proposed by Shapley, but also were located outside our universe, that is, Milky Way. It seems neither side won because it could not be determined at that time if these nebulae (nebulae are fuzzy luminous objects that later were resolved into groups of individual stars) were actually star systems. This debate was settled when Edwin Hubble discovered that spiral nebulae are galaxies located at great distances from our Milky Way galaxy. Hubble's basis for this was data that determined the distance of Cepheids which are stars with variable brightness. By 1947 a total of 151 globular clusters were discovered in the Milky Way. It is estimated that there are at least two hundred, many of which are hidden by dust and gases within the galaxy.

The first globular cluster was discovered by the German astronomer Abraham Ihle (1627–1699) in 1665 and was known as M22. However, his telescope was not powerful enough to separate the individual stars within the globular mass of stars. Later, using a more powerful telescope the French astronomer Charles Messier (1730–1817) observed the globular cluster known as M4 and was able to determine that the cluster was composed of many, many individual stars held together in a ball-shaped cluster by gravity. Note: The M before the number of a cluster refers to its entry in Charles Messier's star catalogue that was published in 1774. Other seventeenth- and eighteenth-century astronomers, including Edmond Halley, Gottfried Kirch (1639–1710), Philippe Loys de Chéseaux (1718–1751), Jean-Dominique Maraldi (1709–1788), as well as Abraham Ihle, were actually discoverers of the globular clusters. Stars in globular clusters are older and less dense than stars in open clusters that are found in the central disks of galaxies. The clusters are composed of many thousands of so-called low-metal stars (such as hydrogen and helium) and are similar to the stars found in the central core of spiral galaxies. They are surprisingly free of gas and dust found in other regions, possibly because the gas and dust were incorporated into stars eons ago. High-density stars, such as those found in globular clusters, do not have the conditions necessary to maintain planetary systems. The globular clusters within the Milky Way are usually found surrounding the core but in an asymmetrical distribution. Shapley estimated the size of the Milky Way galaxy by the amount of light from the central globular clusters. Although his estimations were not accurate due to dust in the galaxy, he did demonstrate that the Milky Way was much larger then previously believed.

See also Hubble

SHARP'S THEORY FOR THE "SPLICING" OF DNA: Biology: *Phillip Allen Sharp* (1944–), United States. Phillip Sharp shared the 1993 Nobel Prize for Physiology or Medicine with Richard Roberts.

Messenger RNA found in eukaryotic cells hybridizes into four sections of DNA that loop from the hybrid regions of the DNA.

As did other molecular biologists in the 1970s, Phillip Sharp believed **eukaryotic** cells (with nuclei) would act similar to prokaryotic cells (without nuclei), where the DNA would form triplets with RNA to provide the codes to form amino acids. After examining the results of his hybrid double strands of DNA/RNA in the adenovirus (the virus that causes common colds), he noted that small sections of the loops that formed from the hybrids broke off and became spliced with the messenger RNA. These then escaped from the cells to become templates for protein production. Sharp and his colleague Richard Roberts determined the "split genes" identified in the adenovirus were common to all eukaryotic cells (which include the cells in the human body). They concluded that over 90% of the DNA was "snipped" out of the strands and became "junk" DNA. This result promised to provide some answers for the problems of genetic splicing related to some hereditary diseases. If this splicing or segmentation of the DNA molecules is better understood and can be controlled, it may be possible to find a cure for some hereditary cancers.

See also Crick-Watson; Roberts; Sanger

SHEPARD'S THEORY OF SUBMARINE CANYON FORMATION: Geology: *Francis Parker Shepard* (1896–1985), United States.

Several forces, including underwater erosion on steep slopes on continental coastlines, turbid underwater currents, underwater slumping/slope failure, and faulting, are responsible for the formation of underwater canyons.

Francis Shepard collected data for fifty years that he used to indicate the possible causes for the giant underwater canyons that are found on the deep sides of continental slopes, often at depths greater than two kilometers below sea level. Many of these large submarine canyons have been carved out of sediment as well as hard crystalline rock. Some of the largest underwater canyons are larger than any land-formed canyon, including the Grand Canyon found in the western United States. There is some evidence that some of these are extensions of land-based rivers that, eons ago, carved out a deep channel. The largest underwater river-type canyon is formed by the extension of the Congo River. It is 500 miles long and 4,000 feet deep. Other examples of submarine river canyons are the Amazon Canyon; the Hudson River Canyon; the Ganges River canyon; the Indus River canyon; three found in California are the Monterey, the La Jolla, and Scripps canyons; and two in the Bering Sea are the Bering River and the huge Zhemchug River canyons. One concept is that margins of continents rose up and then sank. Another idea was that during the ice age sea levels dropped enough to dry up the Mediterranean Sea and exposed much of the major oceans' floors to geological and other type of erosion events. This concept assumes that the canyons were once above water and were formed by erosion of flowing river water.

In Francis Shepard's book *Submarine Canyons and Other Sea Valleys* he clarifies his theory and admits that exactly how submarine canyons formed is still a puzzle, but he offers several complex solutions to the puzzle. He proposes that gravity is basically the force that produces slow movement of coastal and ocean sediments and underwater landslides, as well as deep water turbid currents that erode the canyons over millions of years. Gravity is also responsible for slope failure resulting in mass wasting, slumping, and submarine landslides that occur on steep hills. He claims that these forms of erosion are mostly responsible for forming the submarine canyons. Many geologists do not accept this theory because past history indicates that the sea level has dropped only about 100 meters. Thus, the erosion of canyons many thousands of feet below sea level cannot be explained using Shepard's theory. It is now accepted that gravity related to the degree of down slope of canyon walls form channels that "dig up" and transport loose conglomeratic-type materials from the continental slopes over long time periods by gravity. This material consists of small fragments of larger rocks, sand, and silt that are transported by turbid underwater currents and waves over long distances and thus is the primary mechanism for the formation of these giant submarine canyons.

SHOCKLEY'S THEORY OF SEMICONDUCTORS: Physics: *William Bradford Shockley* (1910–1989), United States. William Shockley shared the 1956 Nobel Prize for Physics with John Bardeen and Walter Brattain.

> *In crystal form, the element germanium will carry an electric current less well than a metal but much more efficiently than an insulator, thus it can act as a semiconductor, which enables it to rectify and amplify electric currents.*

In 1948 William Shockley and his colleagues John Bardeen and Walter Brattain discovered that small impurities within the germanium crystal determine the degree of its conductivity or capacity to carry electricity. This type of material, which allows some electricity to pass through it, is called a *semiconductor*. Later they realized that other crystals, such as silicon, were even better and less expensive semiconductors. Because these devices are solid, they are also known as *solid-state semiconductors*. Shockley soon learned how to vary the small amount of impurities in the crystal's structure, enabling it to be used as a "switch," or as a **rectifier** or **amplifier**. These semiconductor elements when "doped" with small amounts of specific impurities that are composed of atoms with either four or five electrons in their outer shells (orbits) will act as electrical conductors. If arsenic with five electrons in its outer orbit is the impurity used, it will carry the current in the semiconductor, and thus the conductivity is named a n-type conductor (negative). When elements with fewer than four outer electrons, such as boron that has just three outer electrons, are introduced as an impurity, they act like "holes" where electrons are missing. Thus, this is referred to as p-type conductivity (positive, or lack of a negative). The current flows when one electron from a close atom is transferred to fill up this "hole." In doing so, it creates another "hole," which results in these successive positive

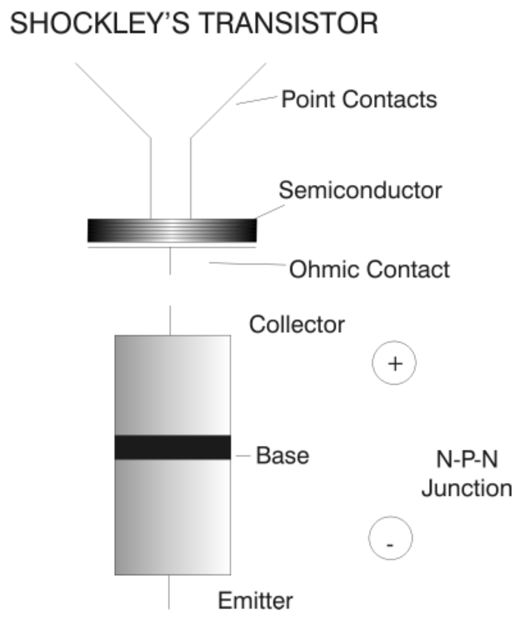

Figure S1. An artist's diagram of Shockley's transistor with an *n-p-n* junction. The *n*-type material carry electrons, while the *p*-type conductivity occurs when the "holes" in the material left by moving electrons are filled, thus allowing the junction to act as a rectifier and transistor to alter and amplify current.

holes being filled with electrons, forming a flow of electricity that can be regulated. Shockley made a "sandwich" of p-type material with n-type material to form a junction, which is known as an *n-p-n junction*, capable of amplifying electrical impulses (radio and TV). This n-p-n "sandwich" junction uses very little electricity as it transmits current across a resistor—thus the name *transistor* (*see* Figure S1).

Transistors replaced glass vacuum tubes in radio and television receivers, resulting in the tremendous miniaturization of electronic equipment, and formed the basis for the current electronics industry.

See also Bardeen

SIDGWICK'S THEORY OF COORDINATE BONDS: Chemistry: *Nevil Vincent Sidgwick* (1873–1952), England.

> *Two electrons from one atom can provide both "shared" electrons to form "coordinated" organic compounds.*

Nevil Sidgwick became interested in the concept of valence as the sharing of electrons in shells of atoms as proposed by Richard Abegg, Gilbert Lewis, and Irving Langmuir. The valence concept is built on Niels Bohr's quantized atom, where the electrons orbit in specific shells (orbits) based on their level of energy and was first proposed to explain how atoms combined to form molecules during inorganic chemical reactions. For example, each of two chlorine atoms shares an electron so that each can have eight electrons in its outer shell (orbit). This means each had seven electrons plus one shared with its close neighbor chlorine atom, thus forming the diatomic molecule of chlorine gas (*see* Figure S2).

Sidgwick's theory stated that similar "sharing" of electrons also occurred in the formation of both complex metal and organic compounds, but this sharing was different from the inorganic "covalent" electron bond, where each atom contributed one electron to the other atom. For this new type of bonding, one single atom could provide both electrons to combine with another atom, forming a new complex molecule. Therefore, he called these complex molecules *coordinated compounds* (*see* Figure S3).

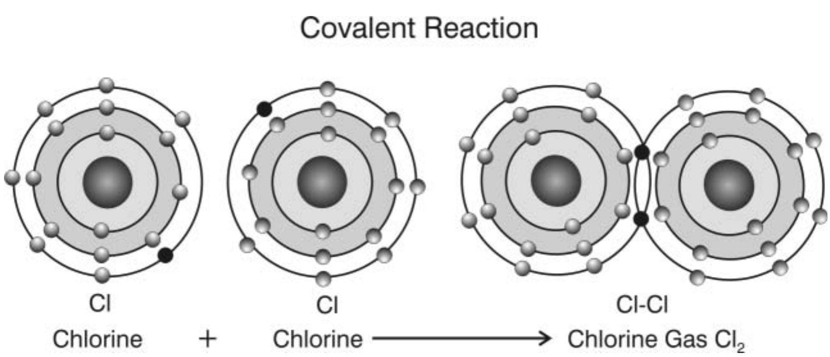

Figure S2. A depiction of a covalent reaction between two chlorine atoms (each with an outer orbit of 7 electrons) sharing two electrons to form a chlorine molecule (Cl_2).

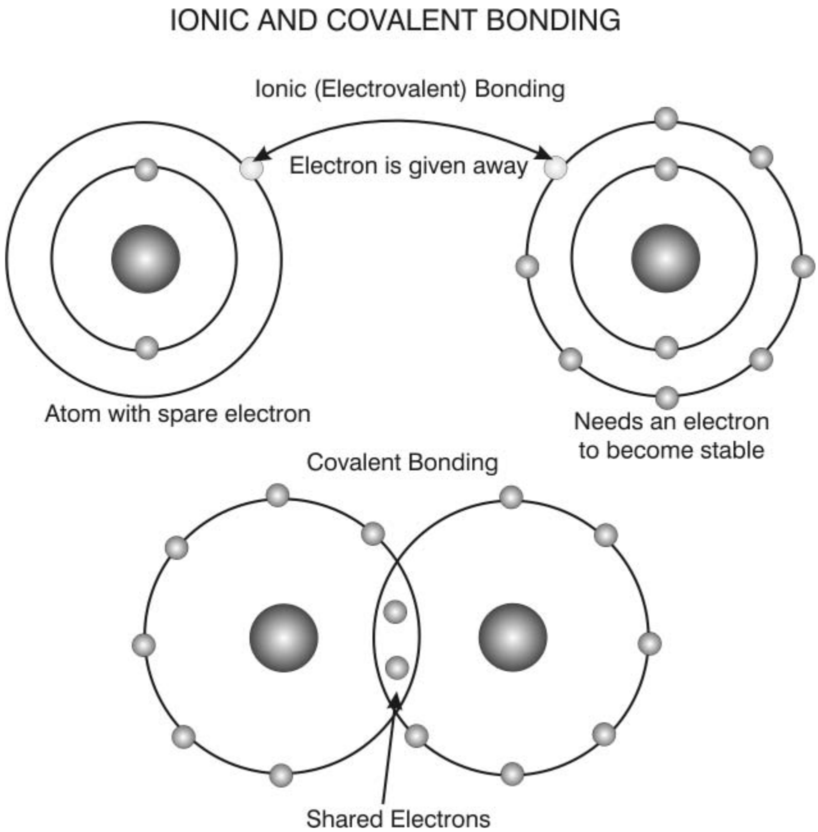

Figure S3. Chemical bonding uses electrostatic forces to form atoms into molecular compounds. Chemical reactions change, break, or re-form these bonds. There are two basic types of bonding: *Ionic* bonding between atoms occur when atoms with a dearth of negative charges in their outer orbits (valence) naturally attract electrons from other atoms to form ions and molecules. *Covalent* bonding occurs when atoms share electrons and each atom contributes one or more electrons to form the covalent bond. In both cases, the end results indicate the atoms have achieved an outer orbit electron configuration to the noble gases (Group 18, VIIA of the Periodic Table of the Chemical Elements).

The concept of coordinated bonds provided a better understanding of organic chemical reactions.

See also Abegg; Bohr; Langmuir; Lewis

SIEMENS' THEORY FOR REGENERATING HEAT: Physics (Engineering): *Carl Wilhelm Siemens* (1823–1883), Germany and England.

Heat can be economized by a regeneration condenser process.

Carl Wilhelm Siemens was one of fourteen children born to a farmer for the estate of the Crown in Germany. He and his older brother, Ernst Werner Siemens (1816–1892), an electrician and industrialist, became famous inventors. As a young man in 1843, Carl Wilhelm emigrated to England, where he lived until his death at the age of sixty. Carl Wilhelm did not believe in the existing theory that heat was a substance called "caloric" but rather accepted the new concept that it was a form of energy. Using this concept, he improved steam engines by economizing heat by condensing it and thus regenerating it. Along with superheated steam, he improved the efficiency of steam engines. Because of technical difficulties, his innovation was not financially successful. Even so, the Royal Society of Arts in Great Britain awarded him a gold medal for his development of the "regenerative condenser." He went on to develop the Siemens–Martin process that used his regenerative furnace, a much more efficient heating system than the open-hearth furnace in which pig iron was heated to the point that its impurities, such as carbon, were expelled. The Siemens regenerative furnace was able to recover enough heat to save about 75% of the fuel required for the process. It operated at a higher temperature by preheating the air used for combustion in a system that extracted heat from the exhaust gases passing through a specially designed brick chimney. By using this heat regeneration process, it became possible for the furnaces to melt steel, which was the first challenge to the Bessemer process. Today, the process of providing adequate heat for making steel is improved by using oxygen in an enclosed furnace or an electric arc-type furnace.

Carl Wilhelm Siemens and his older brother, Ernst, were interested in what at the time was the new field of telegraphy. Telegraphy referred to a new communications system that transmitted and received unmodulated electrical impulses via wire cable connected to transmission and reception stations. The end result: the telegram. Their first underground cable in Germany used **gutta-percha** for an insulation that was vulcanized. However, because the vulcanization process uses sulfur, it caused a reaction with their copper wire, thus destroying the insulation. They moved their business from Germany to England where they improved their techniques and received a contract to lay a telegraph cable from London to Calcutta, India. In the process Carl Wilhelm designed the first cable-laying ship in 1874, called the Faraday that laid 60,000 kilometers of cable throughout the world. The brothers' interest included improving electrical generators with a new type of self-activation dynamo that had numerous applications in the generation of industrial power, lighting, and so forth, for commerce as well as for individual homes. The electrical unit for conductance (the reciprocal of resistance, I or R) is called the *siemens*, in honor of Sir Carl Wilhelm.

See also Carnot; Joule

SIMON'S THIRD LAW OF THERMODYNAMICS: Physics: *Sir Francis (Franz) Simon* (1893–1956), Germany and England.

> *The degrees of freedom for random paramagnetic molecules, which absorb heat from liquid helium, will become zero at the temperature of absolute zero.*

Walther Nernst claimed that for thermodynamic reasons, absolute zero (−273.16°C or −459.69°F) can never be reached because all materials at the absolute zero point would have no entropy, which he believed was impossible. Sir Francis Simon established the third law of thermodynamics (which simply states that it is impossible to cool any object to a temperature of absolute zero kelvin or −273.15°C.) by using a magnetic method of cooling as well as the use of liquid helium. Simon was able to reach the temperature of 0.0000016 K, within about 1/200,000 of one degree above absolute zero by surrounding liquid helium with a magnetic field that, when removed, causes the paramagnetic molecules to orient themselves in a random fashion while absorbing the small amount of remaining heat from the helium. Although Nernst received the 1920 Nobel Prize in chemistry for his concept that one could approach but never achieve absolute zero, it was Simon who established the third law of thermodynamics as the point where all molecular motion ceases—there is absolutely no heat (i.e., no kinetic energy, thus no molecular motion). This is the point where material substances have no degrees of freedom, which is absolute zero (0 K).

See also Nernst

Sir Francis (Franz) Simon was born into a wealthy German merchant's family and attended the universities in Munich, Göttingen, and Berlin, where in 1921 he received his PhD in physics. While at the University of Berlin, he worked with Walther Nernst who developed what was first known as the Nernst theorem or postulate, later known as the third law of thermodynamics. This law states that the entropy of a system at absolute zero degrees kelvin will not exist in a **ground state**. Entropy is the degree of ''disorganization'' or molecular motion (heat) within a system. In other words, absolute zero K of a system cannot be achieved.

During the 1930s anti-Semitism spread throughout fascist Germany causing Simon, who was Jewish, to emigrate to England. In 1933 he was invited to be an assistant professor at Oxford University. While there, his research interests were in using helium to achieve low temperatures, as well as in physical chemistry when he devised a method of separating the isotope uranium-235 from the element uranium-238. Later his work was transferred to the Manhattan Project in the United States. The gaseous diffusion process that he helped develop, that is, separating uranium isotopes, proved important in the development of the atomic bomb.

In addition to his accomplishments in developing a method of achieving low temperatures within a small fraction of a degree of zero degrees K, and his contributions to the gaseous diffusion process for separating U-235 from U-238, he is the only person to receive the Iron Cross from the German government before World War II, as well as a knighthood from the British government in 1954.

SLIPHER'S THEORIES OF INTERSTELLAR GASES AND ANDROMEDA: Astronomy: *Vesto Melvin Slipher* (1875–1969), United States.

Slipher's interstellar gas theory: *There are enormous amounts of dust and gaseous material dispersed between and among the stars and galaxies.*

In the early 1900s Vesto Slipher was the first to make telescopic observations of the great clouds of interstellar material that reflects the stars' light and that is located between the stars. Up to that time, these clouds appeared to the unaided eye as "dust" or "gas." Slipher proposed that these observable but diffuse nebulae (clouds of gas and dust) become luminous due to light from nearby stars that is reflected off the dust and gases in space. He determined this radiation varies, thus altering the brightness of the night sky. Slipher also discovered the existence of the elements sodium and calcium dispersed in interstellar space (*see also* Rubin).

Slipher's theory for the speed of the Andromeda Nebula: *The dark lines of the light spectrum of Andromeda indicate it is approaching us at a tremendous speed.*

Another one of Slipher's important achievements was his determination of the angular velocity of spiral nebulae as they rotate. He did this by measuring the displacement of their spectral lines by using the Doppler effect. By comparing this data, the velocity of moving stellar objects can be determined. One amazing result of using this discovery was that he was able to determine that about half of the spiral nebula that are observable are moving towards Earth, and the other half are moving away from Earth. His measurements of these great velocities helped prove that spiral nebulae were located outside our Milky Way galaxy and helped support the theory of an expanding universe.

For several hundred years, astronomers thought Andromeda was simply a large accumulation of gas concentrated at one location in the sky. In 1612, the German astronomer Simon Marius (1570–1624) was the first to view and describe this fuzzy luminous cloud that he called the Andromeda nebula (*nebula* means "cloud" in Latin). At one time it was also believed that Andromeda might be located in Earth's Milky Way galaxy. Slipher devised a technique using the Doppler effect to measure the radial velocity of spiral nebulae to determine the shift of their spectral lines. For instance, when an object moves away from us, its light's wavelength lengthens toward the red end of the spectrum—thus, the red shift. Conversely, if the object moves toward us, its light's wavelength is shortened to the blue end of the spectrum. In 1912 Slipher determined that the Andromeda nebula is not part of our galaxy but is rather a large galaxy moving toward Earth at a speed of more than 300 kilometers per second (about 200 miles per second). This theory, at first disputed by other astronomers, resulted in a better understanding of the nature of the universe. Slipher used the Doppler shift method to examine the spectra of several dozen extragalactic objects, predating Edwin Hubble's use of the red shift to measure the distance of far objects in the vast universe. Hubble estimated that Andromeda was seven hundred and fifty thousand light-years from Earth. Since then this estimate has been increased to over one million light-years, meaning the light from the Andromeda nebula now viewed by astronomers started its trip over one million years ago. Today, it is estimated there are over one hundred billion galaxies similar to Andromeda in the universe, each containing billions of individual stars.

See also Doppler; Hoyle; Hubble

SMOOT'S THEORY OF A NONUNIFORM UNIVERSE: Astronomy: *George Fitzgerald Smoot* (1945–), United States.

> *There are ''spots'' in the universe that are slightly warmer than the average temperature of the universe. Therefore, the universe is not absolutely isotropic.*

Research from the early 1960s suggested that the universe must be isotropic (exactly the same in all locations). However, at the same time, the concept of an inflationary (ever-expanding) universe, proposed by Alan Guth, required the existence of areas throughout the universe that are less dense and/or with slightly different temperatures. In addition, Guth claimed that the observable inflationary universe could have originated from an infinitesimal "nothing," which later was known as a "singularity." In 1989 a satellite that carried instruments designed to measure differences in radiation at different locations in the universe, as well as the absolute brightness in the sky, provided reams of data that Smoot analyzed. His theory of island structures in the universe is at odds with the isotropic concept of space, but it does agree with recently discovered clusters of galaxies and even superclusters of galaxies. He determined some areas of space are slightly warmer (by 1/30,000,000 of 1°C) than other regions of the universe. Thus, this difference in radiation indicates the universe is not isotropic. His data supported the now widely held theory of the big bang followed by an inflationary universe.

See also Guth

SNELL'S LAW: Physics and Mathematics: *Willebrord van Roijen Snell (aka Willebrord Royen Snellius)* (1580–1626), Netherlands.

> *The refraction of light is the ratio of the sines of the angles of incidence (i) and the angle of refraction (r), and is a constant equal to the refractive index of the medium through which the light travels* (*see* Figure S4).

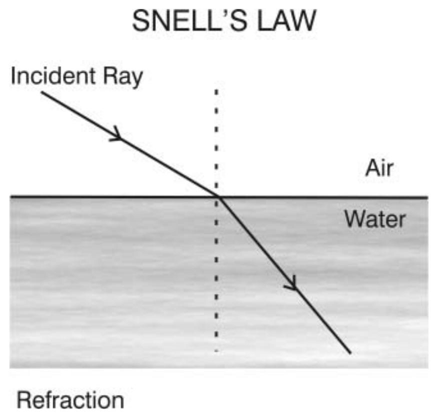

Figure S4. Refraction occurs when a light beam passes the boundary between two substances of different densities.

Refraction is basically the change in direction of a ray of light as it enters the boundary between two different mediums that have different refractive indexes. The refraction index of a substance is dependent on the ability of the substance to bend light.

In Figure S4 the incident light ray traveling through air enters the water at angle "i" to the perpendicular, while the light ray is refracted (bent) as it enters the water at the angle "r" to the perpendicular. The difference in the degree the light ray travels from the air into the medium (water) is based on what is known as the refractive index. This index can be measured and varies from 1 if the light ray travels between two mediums that have the same refractive index. (Note: *The scale for the Index of Refractions of light for some common substance ranges from 1.0000 for the refraction of light in a vacuum, to 1.0003 in air, 1.31 in ice, 1.33 in water, 1.46 in quartz glass, 2.11 in 50% sugar solution, and a diamond which has an index of refraction 2.42.*) Therefore, a light ray traveling from a less dense medium has a higher index of refraction when it travels through a substance of a greater density. This is why a diamond, which is denser than air, has a refractive index of 2.42 that is the greatest refractive index of all gemstones. In other words, the denser the medium compared to air, the greater the bending of light from the perpendicular. Snell's law is used to mathematically express this relationship, that is, 3.00×10^8 m/s (miles per second), which is the ratio of the speed of light in a vacuum to the speed of light in a denser medium. The phenomenon of refraction is responsible for many optical illusions when viewing objects under water—they seem bent and the object's apparent position is not its actual position.

> Willebrord Snell was born in the city of Leiden in the Netherlands. He originally attended the University of Leiden as a law student, but after presenting some lectures in mathematics at the university, he switched to his famous father's profession of mathematics. He contributed to the fields of optics, astronomy, and navigation, as well as mathematics and other areas of science. In 1621 he discovered the basic law of refraction, that is, the bending of light rays that occurs when a light ray changes its speed as it travels from one medium to another of a different density. Although he only lived to be forty-six years of age, he made many contributions to science and mathematics, as well as publishing five books. He improved the work of the ancient scientist Eratosthenes by using a method of measuring the size of Earth by triangulation, which became the basis for the modern science of *geodesy*. He also improved Archimedes' method of estimating pi by drawing a circle and adding polygons to the outside and inside of the circumference of the circle. Snell improved the accuracy of the techniques by using polygons with ninety-six sides that enabled him to correctly calculate pi to 7 places. His contribution to navigation involved the use of *loxodromes* (the path a sphere makes at a constant angle with Earth's meridians).

Optical illusions also occur in the atmosphere when there is a variation in layers of air through which an object is viewed. This optical illusion may account for some sighting of UFOs, "ghosts," and various unexplained objects.

See also Descartes; Fermat

SODDY'S DISPLACEMENT LAW FOR RADIOACTIVE DECAY AND THEORY OF ISOTOPES: Chemistry: *Frederick Soddy* (1877–1966), England. Frederick Soddy received the 1921 Nobel Prize for Chemistry.

Soddy's radioactive displacement law: A *radioactive element that emits an alpha particle (a positive helium nucleus) is transformed into another element with a lower atomic weight, while a radioactive element that emits a negative beta particle (electron) will raise that element's atomic number.*

Frederick Soddy was aware of the particles and radiation that were emitted by radioactive elements and that as their atoms lost either positively or negatively charged particles, these radioactive elements were transmuted "changed" from the original. At this time, the existence of the neutron was unknown. The discovery of the neutron in 1932 by Sir James Chadwick explained the difference in atomic weights for isotopes (elements with the same atomic number but different atomic weights). But up to this time, some confusion persisted relative to what took place during the decay of radioactive elements. Soddy's displacement law of radioactive decay states that heavy radioactive elements, which emit **alpha particles**, will reduce that element's atomic weight by 4. Conversely, if the radioactive element emits an electron, it will have a higher atomic number. Soddy's displacement law provided the information needed for his original theory of isotopes.

Soddy's theory of isotopes: *Some forms of the same elements have similar chemical characteristics (same number of protons) but exist with more than one atomic weight.*

Frederick Soddy believed that many elements were "homogeneous mixtures" of similar elements with similar atomic numbers but for some reason had slightly different atomic weights. He referred to these elements as isotopes, meaning the "same place" in Greek. At that time it was not known that the variances in weights of similar atoms were due to the different numbers of neutrons in atomic nuclei. Soddy demonstrated that two elements, uranium and thorium, are radioactive and will decay into isotopes of lead. Although these two radioactive elements decay in different sequences, their end products are isotopes of lead (lead with different atomic weights). By subjecting uranium and thorium to different chemical reactions, Soddy and his mentor, Sir Ernest Rutherford, arrived at what is known as the *radioactive series*, which explains in detail the decay sequence taken by these elements before becoming stable isotopes of lead. Later in his career, Soddy also believed there were limited sources of hydrocarbon energy on Earth, which culminated in his proposal to use the energy of radioactive elements as a solution for our energy problems.

See also Chadwick; Rutherford

SORENSEN'S NEGATIVE LOGARITHMS REPRESENTING HYDROGEN ION CONCENTRATION: Chemistry: *Soren Peter Lauritz Sorensen* (1868–1939), Denmark.

> *The negative logarithm of the concentration of hydrogen ions in a solution can be used to measure the acidic or basic (alkaline) properties of solutions. This measure is called pH.*

Soren Sorensen's system was one of the first attempts to measure the extent to which a solution was either acidic or basic. To make his concept work, he used negative **logarithms** to determine the concentration of the hydrogen ions (H^+). If the solution has a greater concentration of H^+ ions than OH^- ions, the solution is acidic. Conversely, if the solution has a higher concentration of OH^- ions, it is basic (caustic or alkaline). The pH scale ranges from 0 to 14, with pH 7 being neutral (the H^+ ion and OH^- ions are equal). Solutions decreasing from pH 6 to pH 0 indicate increasing H^+ ion concentration (greater acidity), while a reading ranging from pH 8 to pH 14 indicates solutions of increasing OH^- ion concentration (greater alkalinity). Because the pH scale is logarithmic, each unit increase in pH represents a tenfold increase in the concentration of either the H^+ or OH^- ions for each mole per liter (mol/L). For example, pH $0 = 1 \times 10^0$ H^+ concentration (mol/L), while pH $6 = 1 \times 10^{-6}$ concentration, and for *pH* 14 the H^+ concentration would only be 1×10^{-14}. Conversely, for pH 14, the concentration of the OH^+ ion would be 1×10^0, and for pH 0 the OH^- ion would be only 1×10^{-14} (mol/L). A simpler interpretation of the scale states that if a solution has a pH lower than 7, it is acidic; a pH higher than 7 indicates a basic; and a reading of 7 on the scale means the solution is neutral. This system measures the pH of all solutions in a number of ways, the simplest of which is the use of indicators, such as paper strips, that change color when wetted by the solution. The color change is matched with a color chart to determine the pH value of the solution. A more accurate and less subjective method is the use of a pH meter consisting of a glass electrode sensitive to the H^+ ions, where the reading can be compared to a reference electrode. The pH meter also permits continuous readings, which are not possible with the paper method. Determining the pH level of the acidity or alkalinity properties of solutions or other substances is important to many industrial processes dependent on the exact degree of pH required for some chemical reactions.

SPALLANZANI'S THEORY REFUTING SPONTANEOUS GENERATION:
Biology: *Lazarro Spallanzani* (1729–1799), Italy.

> *If solutions containing microorganisms are boiled over a long period of time and are not exposed to the air, all living organisms will be destroyed.*

The concept of spontaneous generation dates back to the earliest humans and their curiosity about how living things just seemed to appear and grow. In 1668 Francesco Redi, who studied insect reproduction, investigated William Harvey's concept that flies do not just spontaneously appear but are produced from eggs (*see* Redi for details on his classic experiment). In 1745 the British biologist and Roman Catholic priest John Needham (1713–1781) proposed that a "life force" was present in all inorganic matter, including air, which could cause life to occur spontaneously. Therefore, after boiling his chicken broth but leaving it exposed to air, microorganisms grew, "proving" his belief that life could be generated from this "life force." Needham later repeated this experiment, but he sealed off the glass spout of the flask containing the boiled broth. The organisms still grew. Again he claimed to have proved the viability of spontaneous generation. Lazzaro Spallanzani decided that

Needham had not boiled the broth long enough and had not removed the air from the jar before sealing it. Spallanzani improved the experiment by not only boiling the broth longer, but he drew out the air, creating a vacuum in the flask as he continued to boil the broth. He then sealed the flask. No microorganisms grew, which proved Spallanzani's theory that spontaneous generation could not occur without air.

See also Pasteur; Redi

SPEDDING'S THEORIES: Chemistry: *Frank Harold Spedding* (1902–1984), United States.

Spedding's theory for separating the lanthanide elements: *The lanthanide series of elements (numbers 57 to 71) have very similar physical and chemical characteristics; therefore they can only be separated by using ion-exchange chromatography.*

Frank Spedding received his PhD degree from the University of California at Berkeley in 1929 at the beginning of the Great Depression and found that jobs for chemists did not exist. He spent a number of years on several low-paying fellowships including a National Research Fellowship that enabled him to continue his research at Berkeley. He was then hired as a chemistry instructor by the famous American chemistry professor, Gilbert Lewis, who encouraged Spedding to continue his work with the absorption spectra of solids. Spedding combined his ideas related to quantum mechanics to the spectra analysis of molecular structures of compounds that he knew demonstrated a sharp type of spectra in the atoms' and molecules' gaseous phases, whereas solids do not usually produce a sharp spectra. Spedding also knew about the problems of separating and identifying elements commonly called "rare earths" (which are not really rare, but are almost impossible to identify individually) that are found in the lanthanide series of elements 57 to 71. A chemistry professor at the University of Illinois, B. Smith Hopkins (1873–1952), isolated less than an ounce of a few rare earths, which were extremely difficult to come by in a purified form using laboratories procedures. Spedding convinced Hopkins to "lend" him a tenth of a gram from his samples with the agreement that he would do nothing to damage the samples and return them when he was finished with his research. Because he knew that a mineral containing a rare earth, when cooled to about 80 kelvin, gave a sharp-line spectrum, Spedding concluded that this was evidence of the peculiar arrangement of electrons in atoms of the rare earths. Also, by using this arrangement, he was able to determine the symmetry of the atoms in crystals of the individual lanthanide elements. Thus, he was able to separate individual elements of the lanthanides series by using ion-exchange chromatography—a commonly used process during which hard water is percolated down a column of minerals that exchange the ions of elements that cause the water to be "hard" with synthetic resins. Spedding then used this process to separate lanthanide chloride molecules where the lanthanide ions were separated from the chloride ions. In 1933 he received the Langmuir Award that, at that time, was awarded to chemists younger than thirty-one years of age (*see also* G. N. Lewis).

Spedding's thermite theory for purifying uranium: *By using an exothermic type of chemical reaction between uranium and the oxide of another metal, pure uranium can be produced.*

A thermite chemical reaction is an exothermic reaction in which aluminum metal is oxidized by the oxygen of another metal, usually ferrous iron II or ferric iron III. The process also can be a similar mixture of two chemicals, one containing the element oxygen. In a typical thermite reaction powdered aluminum and powdered iron oxide are mixed with a small amount of binder to prevent the two metals from separating. When ignited, an extremely high temperature is produced that cannot be extinguished by water. The reaction with iron II oxide and aluminum follows: $Fe_2O_3 + 2Al \rightarrow Al_2O_3 + 2Fe$. It takes a source that will produce a very high temperature to start the reaction of the mixture. Either a "ribbon" of magnesium metal or a mixture of glycerin and potassium permanganate, when ignited, will produce heat high enough to start an exothermic reaction. The mixture of about 25% aluminum and 75% iron will produce heat capable of welding large steel objects outside the foundry site, such as the undercarriage of train after a wreck, or producing seamless railroad rails after they are laid. Thermite bombs also have been used as weapons of war. Because the fires they start are not easily extinguished (sand must be used instead of water), great damage to cities has resulted.

In the early days of World War II various ideas concerning the building of an atomic bomb were seriously discussed. One of the obstacles was that uranium-238 was not radioactive enough to provide a sustained chain reaction, but the isotope uranium-235 would be pure enough for a chain reaction. Researchers tried several methods of separating the two isotopes of uranium. Frank Spedding came up with the idea of using molten uranium metal in a thermite-like process. In 1942 the process was scaled up, and his team produced two tons of machined cylinders of U-235 that measured 2 inches in diameter and 2 inches long. Part of this production was sent to Stagg Field in Chicago where Spedding was director of the Chemistry Division of the Chicago Manhattan Project. Thus, the first successful atomic pile used the uranium he produced using a thermochemistry-type reaction.

SPENCER-JONES' CONCEPT FOR MEASURING SOLAR PARALLAX: Astronomy: *Sir Harold Spencer-Jones* (1890–1960), England.

> *An accurate astronomic unit (AU) can be calculated by using the position of a minor planet then comparing it to Earth's distance from the sun.*

Cognizant of the fact that the minor planet Eros was to approach Earth at a distance of only 16 million miles on a specific date in 1931, Harold Spencer-Jones received the cooperation of many astronomers worldwide who all at the same time photographed Eros' position. Using these data, he established the solar **parallax** by comparing the radius of Earth from the center of the sun. His figure, 8.7904 seconds of arc, was later corrected to 8.7941 seconds of arc. This provided a more accurate figure for the AU used to measure large distances for objects in the solar system. One AU is approximately 92,956,000 miles, which is the mean distance of Earth from the sun's center. The AU is much too small a unit for measuring great distances in space. The parsec, which equals 3.258 light-years and is the distance a star would be from Earth if it had a parallax of 1 second of arc, and the distance light travels in a vacuum over one year (a light-year) are the current units used for measuring distant objects in the universe. Spencer-Jones also used a very accurate quartz timepiece to determine the period of rotation of Earth on its axis. He concluded that the rotation of Earth is extremely regular but deviates very slightly each year.

See also Cassini

STAHL'S PHLOGISTON THEORY: Chemistry: *Georg Ernst Stahl* (1660–1734), Germany.

> *When substances burn, phlogiston is released. The more complete the burning, the more phlogiston the substance contains and releases.*

Since ancient times, the concept of objects' burning and rusting puzzled philosopher/scientists. In the seventeenth century Johann Becher (1635–1682), the seventeenth-century German alchemist, advanced the concept of phlogiston, which made sense to many people even though phlogiston had no color or taste. The word is derived from the Greek word *phlogistos* that means flammable. The concept was that when an object burned, heat and light were released, while at the same time it became lighter and produced ash. Therefore, the combustible substance "lost" something called phlogiston. About a hundred years later, the German chemist George Stahl improved the phlogiston concept to the point where it became the first rational theory of combustion. For example, when charcoal burned, almost no ash remained, meaning that charcoal contained a great deal of phlogiston, which was released during combustion. When metal was heated over charcoal, a coating or ash, which Stahl called ***calx***, formed on the metal. Conversely, if the metal was consumed by a very hot fire, its phlogiston was freed, leaving behind the ash-like calx. He concluded that the metal must be composed of calx and phlogiston (metal → phlogiston + calx). Therefore, if the process was reversed and calx was heated over charcoal, it "absorbed" the liberated phlogiston from the charcoal to become metal again (phlogiston + calx → metal). He assumed charcoal was rich in phlogiston, and the release of phlogiston from burning substances seemed a rational explanation of combustion. For example, if a burning candle is placed in a closed jar, the air will soon become "saturated" with phlogiston because the candle is pure phlogiston, as evidenced by the absence of ash. This explanation is false. However, Stahl was correct when he claimed the rusting of iron was also a form of "combustion." The phlogiston theory was shattered in the late 1700s when Antoine Lavoisier developed the currently accepted theory of combustion.

See also Cavendish; Lavoisier

STARK'S THEORIES: Physics: *Johannes Stark* (1874–1957), Germany. Johannes Stark was awarded the 1919 Nobel Prize for Physics.

Stark's theory of the Doppler effect on fast-moving particles: *The frequencies of radiation emitted by rapidly moving particles change as the speed of the particles change.*

The Doppler effect results from the change in frequencies for both sound and light. The red shift (Hubble effect) is used to measure the distance and motion of stars. This technique is based on the Doppler phenomenon, where the frequency of the wavelengths of light from a distant fast-moving source tends to "spread" and register as longer waves as it recedes from us and thus appears red. Stark's theory applies the Doppler effect to fast-moving particles such as electrons and photons. These fast-moving particles can be affected by both magnetic and electrical fields, which increase or decrease the frequencies of radiation they produce.

The Stark effect: *A strong electric field can ''split'' spectral lines, which increases the number of lines.*

Johannes Stark was familiar with the Zeeman effect, which used strong magnetic fields to split the spectral lines of electromagnetic radiation with specific wavelengths. Because the electromagnetic spectrum consists of radiation of specific frequencies produced by the relationship between magnetism and electricity, Stark reasoned that if strong magnets can "split" a specific frequency of the spectrum, electricity could do the same. He used a strong electric field to produce a similar "splitting" or multiplying of lines of the frequencies of the electromagnetic spectrum. This was demonstrated to be a quantum effect (small changes), which Stark at first accepted but later rejected. The Stark effect was used to develop techniques to study electromagnetic radiation and subatomic particles.

See also Doppler; Hubble; Maxwell; Zeeman

STEFAN'S THEORY OF BLACK BOX RADIATION: Physics: *Jozef Stefan* (1835–1893), Austria.

> *The rate of emission of electromagnetic energy of a hot body is proportional to the radiating surface area.*

The black box theory is one of the radiation laws that apply to the properties of electromagnetic radiation when it interacts with matter in the universe. A "black box" is a hypothetical body that absorbs all the radiation that it receives. This theory can be expressed mathematically. The radiated *power* expressed as (P) is the rate of emission of the electromagnetic energy of a hot body and is proportional to the radiating surface area (A), and the fourth power of the thermodynamic temperature (T) as expressed mathematically as $j = \sigma T^{-4}$. Where *j* is the power density or heat loss, σ is the Stefan constant, and T^{-4} is the absolute temperature to the fourth power. Stefan's law is better known as the *Stefan–Boltzmann* law because Ludwig Boltzmann, who was one of Stefan's students, indicated that the law was only valid for blackbodies that either absorb or radiate all wavelengths of radiation (the theoretical hollow blackbody that would be a black box with a hole in it that would absorb or radiate all radiation entering it). The Stefan–Boltzmann law can be deduced from other theoretical principles. Even so, the constant proportionality (σ) in the formula was known as the Stefan constant, which, if the body is perfectly black σ will equal 1. Thus, the value of the constant is equal to $5.6697400 \times 10^{-8}\ \mathrm{Js^{-1}m^{-2}K^{-4}}$.

Jozef Stefan was born into a lower-middle-class family who lived in the Austrian Empire. He excelled in his elementary classes and became the top student in physics in his gymnasium (high school). He graduated in mathematics and physics from the University of Vienna in 1857 and later became a professor in the same institution. He was associated with several other institutions including the Vienna Academy of Sciences. He published about eighty scientific articles and originated the law in physics known as the ''physical power law'' related to the radiation from a blackbody. His law of blackbody radiation applies to the radiation from stars that are almost in perfect equilibrium with their environments; thus, although not perfect, it satisfies the conditions as blackbody radiators. Thus, using his law, Stefan was able to determine the temperature of the sun's surface as 5430°C. The Stefan–Boltzmann law was also used to estimate the temperature of Earth as −6°C.

STEINBERGER'S TWO-NEUTRINO THEORY: Physics: *Jack Steinberger* (1921–), United States. Jack Steinberger shared the 1988 Nobel Prize for Physics with Leon Lederman and Melvin Schwartz.

A beam of neutrinos will produce two different types of neutrinos.

The law of conservation of energy states that in an isolated (closed) system, energy cannot be created or destroyed, although it may be changed from one form to another; but the sum of all forms of energy must remain constant. Physicists knew that when neutrons disintegrated and their "pieces" were measured, something appeared to be missing because the sum of the energy (or mass) of the "pieces" did not add up to the original for the neutrons. Physicists also knew that when a nucleus broke down, it emitted a beta particle (high-energy electron) plus a proton, but these two particles did not contain the total energy required by the law for the conservation of energy. In 1931 Wolfgang Pauli suggested that in addition to the electron (beta particle) and proton resulting from the disintegration of a neutron in the nucleus of an atom, another undetected particle must also be ejected. Because this undetected particle has no electrical charge and very little mass, it is difficult to detect. Pauli's theory stated that when the neutron of an atom breaks down, three, not two, particles are ejected (*see* Figure F2 under Fermi). Enrico Fermi mathematically described and named this theoretical third particle *neutrino*, meaning "little one" in Italian. Scientists tagged it as a "ghost particle" because it had yet to be detected except by the use of mathematics. Even so, mathematically it accounted for the missing energy when beta particles (electrons) are emitted from neutrons. Jack Steinberger developed a technique that produced and controlled a beam of neutrinos. This was somewhat of a surprise because neutrinos contain no electrical charge and practically no mass. He used this beam of neutrinos to demonstrate leptons, which are a group of particles that include electrons and neutrinos and come in pairs of opposites, thus confirming the accuracy of his theory. His theory expanded particle physics to explain the electron (e^-) and its opposite, the positron (e^+). In addition, two different types of neutrinos were discovered: the electron neutrino referred to as the *e* neutrino (**v***e*) and the muon neutrino referred to as the μ neutrino (**v**μ). Steinberger's theory also helped to explain spin as a characteristic for these opposite particles. These two types of neutrinos each have a spin of one-half (opposite to each other) and a slight mass of 105.7 MeV. There are two types of muons or mu mesons: one with a positive charge (μ^+), the other with a negative charge (μ^-). Steinberger's theory advanced the concept of the duality of subatomic particles.

See also Fermi; Pauli

STENO'S THEORY FOR FOSSIL FORMATION: Geology: *Nicolaus Steno (aka Niles Stensen)* (1638–1686), Denmark.

The age of fossils can be determined by the manner and time in which solid (formerly organic) bodies are imprinted on other solid (inorganic) bodies.

Nicolaus Steno was one of the first to propose a theory for the origin as well as the nature of the formation of fossils and one of the first to propose that fossils were formed in sedimentary strata laid down in ancient seas. Two important principles are incorporated into Steno's theory of fossils. First, it is possible to identify the first to be solidified: the organic fossil material or the inorganic substance in which it was formed. Using this concept, he determined that *glossopteris*, which are seeds and remains of ancient fernlike plants, left their imprints first on the surrounding "mud" before the mud turned into rock. Because these fossils were a hard substance found within another hard substance, he concluded it was possible to establish the date of the fossil if the date of the rock was known. Glossopteris, also known as "tongue stones," were often confused with shark's teeth because of their shapes. At that time in history, it was assumed they fell from the heavens and were the actual objects, not fossils. Steno was criticized when he claimed that "sharks' teeth" were not actual teeth but rather fossils formed by minerals replacing the original substance. His second principle stated that if both the fossil and the rock material surrounding it were similar, they then could have been formed in the same way at approximately the same time. Steno's theory, an invaluable method for interpreting fossil records, is still used today and is an example of evidence supporting Darwin's theory of organic evolution. Steno is known as the father of paleontology.

See also Darwin

STERN'S THEORY FOR THE MAGNETIC MOMENT OF THE PROTON: Physics: *Otto Stern* (1888–1969), United States. Otto Stern was awarded the 1943 Nobel Prize in Physics.

> *Protons in atoms behave like small magnets and thus assume one of two orientations within a magnetic field.*

Space quantization theory states that atoms can align themselves in only a few directions when they are in a magnetic field. Otto Stern theorized that some atoms, such as those in silver, could align themselves in only two directions rather than in all directions, as proposed by Newtonian physics. Stern and his colleague, the German physicist Walter Gerlach (1889–1979), devised a unique experiment to test this theory. Their device was a magnet with the north pole as a flat surface and the south pole shaped as a knife edge placed close to but not touching the flat north pole surface (*see* Figure S5).

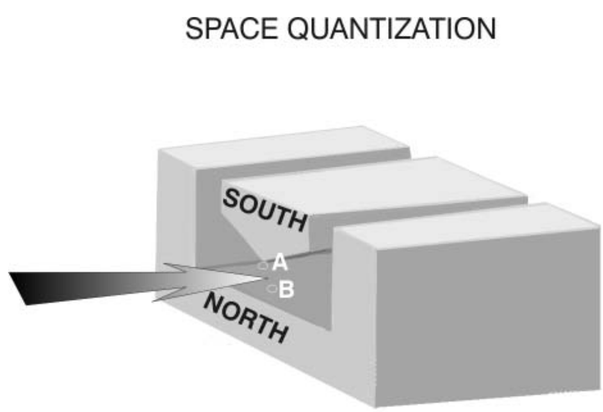

Figure S5. A much stronger magnetic field is produced at *A*, where the sharp edge of the south pole (*S*) of the magnet leaves a gap at *B* (the north pole *N*) which generates a nonhomogeneous magnetic field that produces opposite spin orientations in atoms and is known as space quantization.

This arrangement produced a nonhomogeneous magnetic field between the poles. They directed a beam of neutral silver atoms produced by heating silver metal in a vacuum, which acted like tiny atomic magnets (similar to micro compasses), through a slit between the center of the two poles of the magnet. The nonuniform magnetic field split the thin line of silver atoms being directed across the gap between the north and south Poles. This caused the narrow beam of silver atoms to split into two distinct paths, each representing opposite spin orientations of the atoms (spin-up and spin-down). If the thin line of silver atoms was divided into broad bands, it would have indicated more than two orientations. The restriction of the silver atoms to just two orientations is referred to as *space quantization*. Magnetic resonance imaging instruments used to examine atomic and molecular structures as well as for medical diagnoses are just two of the applications that resulted from Stern's theory.

See also Purcell; Rabi; Tyndall

STOKES' LAWS OF HYDRODYNAMICS AND FLUORESCENCE: Physics: *Sir George Gabriel Stokes* (1819–1903), England.

Stokes' law of hydrodynamics: *A spherical body moving through a viscous fluid at a given speed produces a frictional drag.*

Sir George Stokes applied mathematics to solve many of the problems that concerned contemporary physicists. He developed a complicated equation to explain the hydrodynamics of fluids as a coefficient of viscosity: $6 \pi \eta rv$, where η is the coefficient of viscosity, r is the radius of the spherical body, and v is the speed of the spherical body through the fluid. This computation for the coefficient of viscosity applies only for normal conditions; the law breaks down at extreme temperatures and pressures. Nevertheless, Stokes' law of hydrodynamics is applicable in many industries (e.g., sending oil through pipelines and mixing of liquids).

Stokes' law of fluorescence: *The wavelength of fluorescent radiation is greater than the wavelength of the radiation causing the fluorescence.*

Michael Faraday created a vacuum inside a closed glass jar and then passed an electrical current through the vacuum. He assumed that because the air had been removed, nothing remained inside the jar to stop or slow the flow of current. However, he noticed a greenish glow formed on the inside of the glass as the current was turned on. Sir George Stokes named this phenomenon *fluorescence*, which now refers to any visible light produced by fast collisions of radiation (light, photons, electrons) with matter. It was impossible for Faraday to evacuate all the gas molecules from the glass vessel; therefore the concept of electricity as a fluid was not realized. Stokes proposed his law after another scientist noted that a fluorescent beam could be diverted by exposing it to a magnetic field. He concluded that the source of radiation (electricity) that caused the fluorescence was always of a lesser wavelength than was the actual wavelength of the fluorescent light itself. This law is applicable only under certain conditions of atmospheric pressure within an evacuated glass container and the concentration of gaseous molecules within that container. Stokes' law and this concept pioneered the development of the Geissler tube, computer monitors, and TV screens.

See also Faraday; Fraunhofer

STONEY'S THEORY OF THE ELECTRON: Physics: *George Johnstone Stoney* (1826–1911), Ireland.

> *Electricity is composed of small units of fundamental particles, as is matter, and these units can carry electric charges.*

George Stoney was aware of Svante Arrhenius' work on ionic dissociation as related to solutions of certain substances (e.g., salts that act as electrolytes and carry electric current by ionic dissociation). Arrhenius explained that the salt dissolved to form ions, which could then carry electrical charges (*see* Figure A7 under Arrhenius). Thus, a better understanding of the structure of the atom resulted. George Stoney's theory states there is an "absolute unit" of electricity with just one type of charge, and it is carried from atom to atom when an electric current flows through a conductor. In addition, these charges always exist in a ratio of whole numbers, never fractions of a unit. He based his theory on the calculated mass of the hydrogen ion given off during electrolysis. Stoney coined the term "electron" to describe this basic negative unit of electricity that could be carried by a single atom or even a group of atoms. Several years later the science community accepted his term electron (*see* Figure T1 under Thomson).

Using this knowledge, Stoney determined there were two different types of molecular motion. One relates to the relative motion of gas molecules to each other that does not result in a spectrum when exposed to radiation. The other is the internal, random motion of molecules in a substance that will produce spectral lines related to the type of substance involved.

See also Arrhenius; Helmholtz; Thomson

STRASBURGER'S LAW OF CYTOLOGY: Biology: *Eduard Adolf Strasburger* (1844–1912), Germany.

> *New nuclei of cells arise from existing cell nuclei, and through a process of mitosis, they carry factors responsible for heredity.*

Eduard Strasburger based his research on plant reproduction. He was the first to describe the embryo sac in gymnosperms (conifer/pine trees) and to recognize that angiosperms (flowering plants) reproduce by double fertilization (when the two nuclei from a pollen grain fuse with two nuclei of the embryo sac). His law of cytology, in addition to cell division, described the division of nuclei to form new nuclei in plant cells. The law relates to the study of the growth, structure, reproduction, and chemical makeup of cells and basically states that new cells arise from existing cells. Strasburger's concept of mitosis occurring in the nuclei of plant cells was related to the division of these nuclei following the same principle as that of his law of cytology. From this concept of mitosis, he inferred there were factors of heredity, with which he was not completely familiar, that divided during the process of mitosis as the nuclei of plant cells divided. In mitosis, each chromosome is divided in half so that the two new (daughter) cell nuclei are exactly the same as the mother cell's nucleus. Strasburger also postulated that internal physical forces (i.e., hydraulics), rather than physiological factors (cell functions), are responsible for fluid (sap) being transported in the trunks of trees and stems of plants.

See also Schleiden; Schwann

STRUVE'S THEORY OF INTERSTELLAR MATTER: Astronomy: *Otto Struve* (1897–1963), United States.

> *Interstellar matter appears more diffused than localized throughout the universe.*

Otto Struve was the grandson of the German astronomer Frederich Struve (1793–1864), who first used **parallax** to estimate the distance from Earth to the bright star Vega. The elder Struve's major contribution was the discovery and cataloging of over three thousand binary (double) stars. Otto Struve performed spectroscopic analyses of the binary stars recorded by his grandfather and also examined the structures and atmospheres of other stars and objects. His most important theory related to just what and how much "stuff" existed in the great distances of space separating the stars and galaxies. In 1937 he discovered that the vastness of space contained great amounts of ionized hydrogen. Other elements were also found, such as helium and calcium. More recently, some astronomers have estimated that over 90% of all the mass (matter) in space is "dark matter." Thus, it cannot really be seen because it neither gives off nor reflects light.

See also Arrhenius; Hoyle

SUESS' THEORY OF CONTINENTAL DRIFT: Geology: *Eduard Suess* (1831–1914), Austria.

The southern continents of Earth (Africa, South America, Australia, India) were once combined as one large land mass.

Eduard Suess spent years studying the similarities of geological and plant fossils on the continents of Africa, Australia, and South America and the subcontinent of India. He observed similar geological structures, including mountain ranges, regions of volcanoes and earthquakes, and coastlines for these landmasses, as well as examples of the ancient fossil ferns known as glossopteris that existed in the Carboniferous period of earth's development. Based on these clues, he derived his theory of a great supercontinent he named Gondwanaland, after the Gonds of ancient India. Alfred Wegener developed a theory for a similar supercontinent he named Pangaea (*see* Figure S6).

Suess' theory stated that these four southern land areas were once joined, and, since separation, still exhibit a pattern that indicates their common origin. More recently,

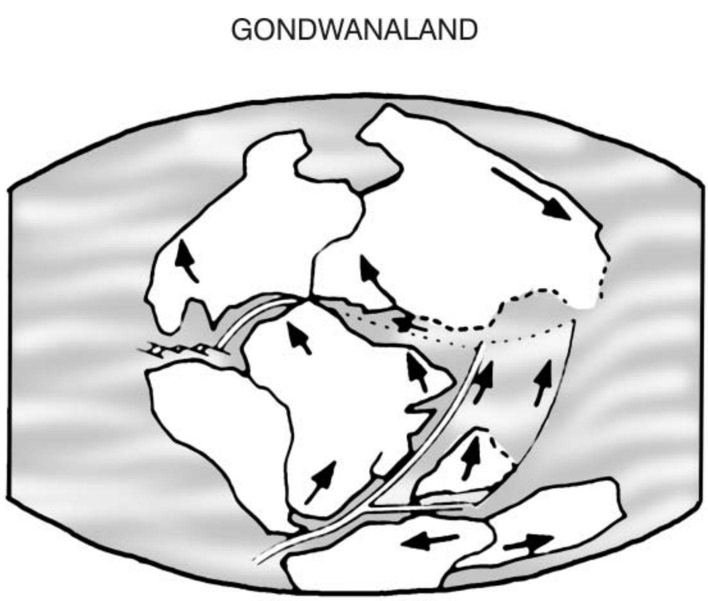

Figure S6. Eduard Suess' Gondwanaland, similar to Wegener's theory of the supercontinent Pangea, began to separate over 200 million years ago, resulting in the formation of the modern continents. Their concepts of continental drift led to the modern science of plate tectonics.

computer models of the coast margins, mountains, and other formations of these continents validate his theory. Suess' theory is an important concept for understanding continental drift in the science of plate tectonics.

See also Wegener

SWAMMERDAM'S THEORY OF PREFORMATION: Biology: *Jan Swammerdam* (1637–1680), Netherlands.

All parts of adult animals are formed at the beginning of the egg's development.

The theory of preformation asserts that all the parts of animals are present in the female's eggs at the time of conception, or, as stated by some scientists in the seventeenth century, a tiny homunculus existed inside either the undeveloped female ovum (ovists) or the male sperm (spermatists) and was composed of all the parts of an adult human. Jan Swammerdam, a devoted microscopist, was the first to use the microscope in the study of zoology. He conducted excellent studies of insects and other smaller animals and was also the first to identify cells in frogs' blood. Swammerdam based his theory of preformation on the metamorphosis process of insects, which he dissected with excellent skill. He observed rudimentary parts (wings, legs, eyes, etc.) of adult insects inside the pupae and cocoons. He claimed a caterpillar did not metamorphose into a butterfly or moth but rather continued to grow into an adult from parts existing in the caterpillar stage. He claimed the same for a tadpole changing into an adult frog (i.e., all of the body parts were contained in the egg). The preformation theory was generally accepted into the early nineteenth century until the epigenesis theory developed. Proponents of the epigenesis theory believed the egg is undifferentiated, and development occurs throughout a series of steps after fertilization by a sperm. This is basically the theory that is accepted today. Karl Ernst von Baer's concept of the formation of a "germ layer" in the eggs of mammals, out of which all the embryonic organs develop, was the final death knell of the preformation theory. Moreover, Swammerdam's insect studies provided him with evidence that disproved the theory of spontaneous generation as an explanation for the origin of life.

See also Baer; Haeckel

SZILARD'S THEORY OF NEUTRONS SUSTAINING A CHAIN REACTION: Physics: *Leo Szilard* (1898–1964), United States.

When the nuclei of certain heavy elements each absorb a single neutron, they will split into two nuclei of different elements, and in the process emit two additional neutrons. Thus, if such an element is concentrated in a critical mass, enough neutrons will be produced to create a sustaining nuclear chain reaction, releasing a great deal of energy.

Leo Szilard followed up on the research on fissionable uranium conducted by Lise Meitner, Otto Frisch, and Otto Hahn. Once he knew it was possible to bombard uranium nuclei with slow neutrons to cause the nuclei to fission (split) and that this reaction would produce more neutrons than were absorbed by the nuclei, he was convinced a sustainable chain reaction was conceivable. In 1933 Szilard fled Germany to England, where he filed a patent for the neutron chain reaction, which he later assigned to Great Britain. In 1938, he arrived in the United States, where he attempted to convince the U.S. government and scientists to develop an atomic bomb because he was convinced the German government was doing the same. He and other scientists persuaded Albert Einstein to send the famous August 2, 1939, letter to President Franklin D. Roosevelt describing the potential for developing the atomic bomb and the urgency for doing so. Despite Szilard's continued work with the atomic bomb, including the idea of a breeder reactor that produces more radioactive material than it uses as fuel, he strongly opposed the use of atomic weapons. He is known as a "scientist of conscience."

See also Chadwick; Einstein; Fermi; Hahn; Meitner; Oppenheimer; Rutherford; Teller

T

TAMM'S THEORY OF THE CHERENKOV EFFECT: Physics: *Igor Yevgenyevich Tamm* (1895–1971), Russia. In 1958 Igor Tamm shared the Nobel Prize in Physics with the Russian physicists Ilya Frank (1908–1990) and Pavel Cherenkov (1904–1990) for explaining the Cherenkov phenomenon of radiation.

When high-speed particles (electrons) pass through nonconducting transparent solids at speeds faster than light passes through the same solid, radiation is emitted.

Igor Tamm's theory is based on the quantum theory of diffused light in solid bodies. Although these high-speed particles cannot travel faster than the speed of light in a vacuum (nothing can), they do pass through certain types of solids and liquids at speeds approaching that of light (186,000 miles per second in a vacuum). At the same time, light travels through the same substances at a slower rate of speed than do high-speed particles (electrons). For instance, light traveling through water or a crystal does so at a speed less than its (light's) speed in a vacuum, whereas the speed of a high-energy electron can surpass the speed of light in water or a crystal. (The speed of light in a vacuum is 299,793 kilometers per second; in water, light's speed is only 224,900 km/s, and when traveling through a diamond [with a high index of refractions], the speed of light is only 124,000km/s.) Tamm's theory explained Cherenkov radiation as being similar to a shock wave produced when an object moves faster than sound through air (e.g., a bullet or jet airplane going faster than sound; *see* Mach). For sound and Cherenkov radiation, the velocity of the object (particle) passing through the medium is greater than the shock wave created by the object's motion. This explains why water surrounding the core of nuclear reactors glows an eerie bluish/green color and why there are "showers" of cosmic radiation on Earth. Detectors designed to count Cherenkov radiation measure the strength of high-speed particles and can also determine their velocities, which almost reach the speed of light. Tamm's explanation of the

Cherenkov effect enabled physicists to understand better the operation of nuclear reactors, as well as the nature of cosmic radiation.

TARTAGLIA'S MATHEMATICAL SOLUTION TO CUBIC EQUATIONS:

Mathematics: *Niccolo (Niccoló) Fontana, known as Tartaglia* (c.1499–1557), Italy.

> *The insertion of a cosa ("a thing"), which represents an unknown quantity, into an equation can assist in solving certain cubic-type equations.*

Born in Brescia in either 1499 or 1500, Niccolo was six years old when his father, a mail deliverer, was murdered during his rounds, leaving the family in poverty. When Niccolo was about twelve years old, he was almost killed during the French invasion of Brescia (the Republic of Venice) that killed forty-six thousand residents. During this slaughter, which reportedly only lasted seven days, a French soldier who attacked Niccolo with a saber sliced into Niccolo's jaw and palate. Too poor to afford a doctor, his mother nursed him back to health. He was left with a serious speech impediment and stutter, and thus accepted the name "Tartaglia," which means "stammerer," the appellation by which he was known for the rest of his life. Tartaglia became a self-taught mathematics teacher who had an extraordinary ability in advanced mathematics. During his years as a teacher in Venice he entered many debates among mathematicians. The first person to solve cubic equations algebraically was a Bolognese mathematician known as Scipione del Ferro (1465–1526). While del Ferro kept this information a secret during his lifetime, on his deathbed he told his assistant, Antoniomaria Fior (dates unknown) his solution. At that time only one solution was known because negative numbers were not used in those days. This type of equation is now known as $x^3 + mx = n$. Tartaglia discovered how to solve more than this single-type cubic equation using squares and cubes as related to numbers, that is, $x^3 + mx^2 = n$. A contest was arranged between Fior (who considered himself a great mathematician) and Tartaglia in which each would put up a sum of money to submit to the other thirty different problems involving cubic equations. Tartaglia submitted a variety of questions, all different and based on his use of squares. On the other hand, Fior had only been given by del Ferro the solution for one type of equation that did not use squares. Tartaglia was inspired and solved his thirty equations in about two hours, while Fior was unable to complete his set of questions.

This seemed to solve the question of who was the best mathematician, but the solution worked out by Tartaglia created another controversy. It seems that Tartaglia shared his solution in confidence with another mathematician by the name of Gerolamo Cardano, who promised to keep Tartaglia's secret. However, when Cardano learned (mistakenly) that it might have been del Ferro, and not Tartaglia, who first solved the cubic equations, he felt no longer bound by his secret agreement and published his methods. Cardano noticed that Tartaglia had used the square root of a negative number in his solutions. This led to a contest between Tartaglia and Cardano. Cardano did not show up for the contest. Instead, he sent his assistant Lodovico Ferrari (1522–1565) who won this second contest. This resulted in the end of Tartaglia's career as a professor of mathematics, as well as his source of income. An interesting consequence followed as a result. When Cardano published his results, it led to the establishment of the policy that the first person to publish the results of an experiment, discovery, or invention, and not necessarily the first person to actually conduct the experiment or who had made the discovery, is the one given credit. This policy is still in effect today. During the remainder of his life, Tartaglia harbored a great resentment toward Cardano. Today, Tartaglia, del Ferro, and Ferrari are all given credit for the work that resulted in the solutions of cubic and quadric equations.

Tartaglia made other contributions to mathematics, arithmetic, and geometry, including his study of Pascal's triangle and his study of tetrahedrons. His other accomplishment was his translation of Euclid's *Elements* into modern Italian. He also made mathematical improvements in the military sciences including ballistics. Tartaglia died in poverty in Venice where he had lived most of his life.

See also Cardano

TATUM'S THEORY OF GENE-CONTROLLING ENZYMES: Biology: *Edward Lawrie Tatum* (1909–1995), United States. Edward Tatum shared the 1958 Nobel Prize for Physiology or Medicine with George Beadle and Joshua Lederberg.

> *Specific genes are responsible for the production of specific enzymes that control particular biochemical reactions in living organisms.*

Edward Tatum began his experiments by inducing mutations in the genes of the fruit fly. He extended this concept by exposing particular types of bread mold to X-rays to induce mutant genes in the mold. He discovered that when these mutant molds were grown in different types of media, they were affected differently according to varying types of nutrients in the growing medium. He then crossbred these distinct mutant mold genes, noticing that their diet peculiarities were inherited according to the standard Mendelian percentages (*see* Mendel). Tatum and a colleague theorized that particular genes are responsible for specific enzymes in living organisms. Enzymes act as organic catalytic proteins found in living cells that control and regulate the chemical process of life. From this they concluded that all chemical processes taking place in plant and animal cells are controlled and regulated by genes.

See also Clark; Delbruck; De Vries; Lederberg; Mendel

TAYLOR'S THEORY OF GRAVITATIONAL WAVES: Astronomy: *Joseph Hooton Taylor, Jr.* (1941–), United States. Joseph Taylor shared the 1993 Nobel Prize in Physics with Russell Hulse.

> *When a binary pulsar is influenced by a nearby massive object, the pulsar changes its orbital period, thereby producing gravitational waves.*

Einstein used his theory of general relativity to predict that when a massive body rapidly accelerates, it will radiate gravitational waves. Such "waves" produced by accelerating stellar bodies are much too weak to be detected on Earth, and thus are still theoretical. Taylor and his student, Russell Hulse (1950–), observed a binary pulsar, which is a pair of massive bodies whose orbits intersect and whose gravities affect each other's velocities and thus their orbital periods. Taylor and Hulse's pulsar was located about sixteen hundred light-years distant from Earth in space, so the theoretical radiation of its gravity waves was much too weak to reach Earth. They continued to watch this observable pulsar and its companion, a dark neutron star, and assumed their near approach to each other would cause a slight change in the pulsar's acceleration and its orbit. This change in acceleration should be detectable over a period of time as a very minor alteration. After several years of analyzing his observational data, Joseph Taylor detected a very slight decrease in the pulsar's orbital period. He claimed the data supported Einstein's theory for the existence of gravitational waves. Even so, no direct radiation gravitational waves from pulsars or any other deep space objects have been measured on Earth.

TELLER'S THEORY FOR THE HYDROGEN BOMB: Physics: *Edward Teller* (1908–2003), United States.

> *The production of X-rays from a fission bomb will produce the pressure and temperature required for a nuclear fusion reaction.*

As the atomic (fission) bomb was being developed, Edward Teller, a nuclear physicist, was already contemplating the design for a hydrogen (fusion) nuclear bomb. The distinctions between the two types of nuclear weapons are important. "Atom bomb" is really a misnomer because atomic reactions involve the outer electrons of atoms and molecules during ordinary chemical reactions. Thus, they are chemical in nature—not nuclear. It is the nuclei of atoms that are involved for both types of nuclear weapons—the so-called atomic and hydrogen bombs. What is commonly referred to as the "atom" bomb involves the fission (splitting) of nuclei of heavy, unstable radioactive elements (e.g., uranium-235 or plutonium-239), which releases enormous energy and radiation, whereas the "hydrogen" bomb is the fusion or combining of nuclei of lighter elements to form nuclei of heavier elements, which also releases great quantities of energy but less radiation.

After World War II, U.S. President Harry S. Truman, concerned that the Russians also had developed and exploded their first "atomic" bomb, encouraged the development of the "hydrogen" bomb for national security. Previously Teller and other scientists had studied various designs for such weapons. Teller proposed three different designs, two of which proved impractical. The third seemed promising until a theoretical mathematician, Stanislaw Ulam, pointed out that Teller's design was not only impractical but much too expensive. Together they developed a further model that overcame the physical and economic problems of the other designs. One problem was that fusion, unlike fission, could not occur under normal conditions of temperature and pressure. Great force was required to slam the positively charged nuclei of hydrogen (protons) together to overcome their natural repulsion. The fusion reaction, which is also referred to as **thermonuclear**, requires tremendous heat and pressure to complete the reaction (e.g., the sun's conversion of hydrogen nuclei into helium nuclei).

Ulam proposed construction of the fission (atomic) bomb around the H-bomb to provide the force necessary to fuse "heavy" hydrogen atoms (with two protons in their nuclei) together to form nuclei of helium. Teller improved Ulam's concept by devising a "mirror" to focus and concentrate the X-rays produced by the A-bomb surrounding the H-bomb to produce the force necessary to start the fusion reaction. The following nuclear fusion reaction occurs: ${}_1H^2 + {}_1H^2 \rightarrow {}_2He^4 + \rightarrow$ Energy. There are two types

There is a little-known story involving academic physicists, including Edward Teller and a number of other top tenured physicists who were called upon by the U.S. Department of Defense for advice on aspects of the physics of war. They met in secret to discuss not only the possibility of an H-bomb, but other physics-related problems beyond the capabilities of the Defense Department. Organized in 1960, this group called themselves ''the Jasons,'' which is an acronym for July-August-September-October-November. ''Jason'' is also related to the Greek myth of Jason and the Argonauts. Top physicists in major research universities used the summer months to conduct most of their research work. The first groups did meet during the summer, and later for short periods during the academic year. However, they did not want it known that they were doing research defense work for the U.S. government, particularly because it was *applied* research—not *basic* research about the nature of matter and force that drives the universe. The applied research and technology for war not only makes use of knowledge gained by basic research, but involves personal moral decisions as well. Most of the thirty to sixty scientists who agreed to be part of the Jasons received top government clearance.

During World War II there were a number of top physicists who were patriotic and worked for or advised the federal government on war-related science policies, particularly on the Manhattan atom bomb project. After the war they returned to their universities and their pursuit of basic science. By the time of the Vietnam War and into the 1960s top scientists again became consultants to the Defense Department, but in a much more secret capacity, primarily because of the Cold War political mentality. A number of the former Manhattan Project scientists, as well as younger people, met in the summer of 1960, as well as subsequent summers, to help solve highly classified problems for the U.S. government in several war-related areas, including intelligence gathering. Although most of the scientists had security clearance, they were given additional freedom to highly classified information, leading to breakthroughs over the next forty-plus years in the areas of high-tech use of electronics on the battlefield that included advanced radar, as well as a means of underwater communications with our ships and submarines worldwide. They also worked on the concept of the ''Star Wars'' warning system, as well as on the now-timely issues of global climate change, electronic barriers that can be used on battlefields, as well as on the Mexican border, and numerous outer space–related operations. Animals, including dogs, honeybees, and others were trained to detect (smell out) hidden bombs and landmines. More recently, departments within various government agencies have taken over much of the work done by Jason scientists in the past. The number of Jasons who are Nobel Prize winners is impressive. They include: Steven Weinberg, Murray Gell-Mann, Hans Albrecht Bethe, Luis W. Alvarez, Eugene Wigner, Charles Hard Townes, and Val Fitch, among others.

of heavy hydrogen, deuterium D–2 and tritium T–3, both of which are used in fusion reactions because they contain extra neutrons in their nuclei (*see* Figure O1 under Oliphant). The atomic weight of two hydrogen-2 atoms is 4.0282, whereas the atomic mass of a helium-4 atom is 4.0028, representing the loss of 0.0254 mass units when hydrogen nuclei fuse to form helium nuclei. This may seem like a minute loss of mass to convert to energy ($E = mc^2$), but when trillions of nuclei are involved in a fusion reaction, this "extra" or leftover mass is converted to about ten times the energy released by a typical atomic (fission) bomb. The first successful fusion hydrogen bomb was detonated by the United States in 1951. Ulam and Teller both claimed it was their own concept to use an atomic bomb to "trigger" the H-bomb. Although many scientists gave Ulam the credit, by this time Teller had become a strong political advocate for developing thermonuclear weapons as a deterrent factor and became known as the father of the hydrogen bomb.

Teller and other advocates of national nuclear polices attacked those who opposed the U.S. policy on nuclear weapons. One of the major developers of the fission (atomic) bomb, Robert Oppenheimer, was horrified at the prospect of using the much more destructive hydrogen bomb in warfare and had his career cut short by opposing Teller's position on nuclear weapons. Edward Teller proceeded to encourage scientists to develop thermonuclear weapons and the strategic defense initiative as a means to protect the United States from long-range missile attacks.

See also Curies; Fermi; Hahn; Meitner; Oppenheimer; Pauli; Rutherford; Szilard; Ulam

TEMIN'S THEORY FOR TRANSCRIBING RNA INFORMATION INTO DNA: Biology: *Howard Martin Temin* (1934–1994), United States. Howard Temin shared the 1975 Nobel Prize for Physiology or Medicine with David Baltimore and Renalto Dulbecco.

> *In addition to genetic information ''flowing'' from DNA to RNA, a special enzyme makes it possible for DNA to receive information from RNA, thus allowing DNA to provide crucial information needed for cell growth.*

While conducting research with cancer cells in chickens, Howard Temin discovered a new enzyme. He named it *reverse transcriptase* because it could reverse the flow of genetic information that at one time was believed to proceed only in one direction, from **DNA** to **RNA**. This DNA-to-RNA sequence was referred to as the "central dogma" because this sequence was required for DNA to replicate itself. This concept was generally accepted by all molecular biologists. Temin's new enzyme "transcribed" the RNA into DNA, which improved DNA's effectiveness in controlling the processes of cell metabolism. At about the same time, David Baltimore independently made the same discovery.

See also Baltimore; Dulbecco; Gallo

TESLA'S CONCEPT OF HIGH-VOLTAGE ALTERNATING CURRENT: Physics: *Nikola Tesla* (1856–1943), United States.

> *High-voltage alternating current can be transported more efficiently over long distances through wires than can direct current.*

In the early 1880s Thomas Edison developed the direct current generators and distribution system used by his Edison Electric Light Company in New York City. It revolutionized the use of electricity but had one major drawback: it had to be generated near the site where it was to be used. This made it useful for lighting compact cities, but since direct current (**DC**) lost much of its energy when sent over wires for some distances, it was an impractical system. Another problem with direct current was that DC dynamos (generators) and motors required a commutator with wire "brushes" to provide electrical contact with the armature and terminals. This arrangement required constant maintenance because the brushes needed frequent replacement. Nikola Tesla's concept solved these problems by using a new system of dynamos (generators) and transformers that could produce current that alternates (**AC**) direction many times per

> With the scientific and engineering worlds, and the courts, extending to him (and not Edison) a clear title to the honor of being the great pioneer discoverer and inventor of the principles and machines that created the modern electrical system, Tesla stands without rival as the genius who gave the world the electrical power age that made our mass-production industrial system possible. The name Tesla should therefore, in all right and justices, be the most famous name in engineering world today. (From *Prodigal Genius: The Life of Nikola Tesla*, by John O'Neill. Cosmos Classics. 2006, p. 117).

second and could be "boosted" to high voltages by transformers, enabling it to be sent over longer distances. An interesting result was that in the 1890s William T. Love (dates unknown) began digging a canal on land that he owned to circumvent Niagara Falls. He planned to use this diverted water to generate direct (**DC**) electricity for industries that could be located near his canal and thus at a greater distance than industries restricted to the falls area due to the limits of direct current. Nikola Tesla's AC system interrupted the project, and the ditch was later filled in with waste material and became known as the infamous Love Canal. Today alternating current in the United States has a 60-cycles-per-second (Hz) rate of changing direction, at 120 volts with relatively high ampere current, while much of the rest of the world uses 50-cycle (Hz), 240 volts with low ampere current.

Nikola Tesla is best known for his insightful technical knowledge of electricity, which he applied in developing many inventions, some of which were years ahead of their time. Among them are the Tesla coil/transformer used in radios and TV sets, the induction (brushless) motor used in computer hard disk drives (as well as almost every other application where motors are required), telephone repeaters for long-distance phone lines and the transatlantic cable, and wireless communication devices now used in cellular phone systems. A partial list of Tesla's almost eight hundred patents include 7 patents related to direct current generators and motors; 39 patents related to electric transmission of power, dynamos, motors, and other systems; 28 patents for high frequency devices for control of electrical systems; 76 patents for wireless systems such as radio, wireless telegraph, and tuning devices; 26 patents for steam turbines, pumps, oscillators, and speedometers. In addition to his many inventions, he should be given credit for additional theories. For instance, he not only theorized but also demonstrated that Earth itself is a source of useful power. He experimented with using Earth as a resonator that could build up frequencies that might be able to communicate wirelessly worldwide as well as destroy surface buildings. His many inventions with light, wireless communications, and electrical systems were forerunners of our present-day technologies.

See also Ampère; Edison; Faraday; Oersted; Ohm; Volta

THALES' THEORY THAT WATER IS THE BASIS FOR ALL THINGS: Philosophy: *Thales of Miletus* (c.625–547 BCE), Greece.

All material things are derived from water.

Thales of Miletus is considered the first Greek philosopher/natural scientist who was educated in the Milesian School for natural philosophers. He also founded a school of natural philosophy in Ionia, a city on the Aegean Sea in Asia Minor. There is a distinction between the Milesian School and the Ionian School. The Ionian included the philosophies of both the Milesians and other Ionian philosophers, for example, Heraclitus of Ephesus (c.535–475 BCE) who believed in ethereal fire from which all things originated and returned in a never-ending process. Thales is known more by stories and folktales than he is by tangible evidence for his thoughts. His accomplishments led to the beginnings of geometry, astronomy, and natural science in general. He is given credit for establishing proof of the claim that a circle, when divided into two equal halves, is so divided by its diameter (this is one theorem neglected by Euclid three hundred years later). He is also credited with predicting a solar eclipse in the year 585 BCE. He believed the question of composition as well as the origin of all material things was connected as the same question, and the answer is water. He chose water because of its importance to the growth and nurture of all living things, and its importance in the lives of the ancient Greeks.

See also Euclid

THEOPHRASTUS' CONCEPTS FOR PLANT CLASSIFICATION: Biology: *Theophrastus* (c.372–287 BCE), Greece.

Plants can be distinguished and classified according to their structures and physiology.

Theophrastus, a student of Aristotle, became the head of the Lyceum in Greece upon the death of Aristotle. One of Aristotle's great achievements was his classification of animals as known at that time. Theophrastus used some of Aristotle's techniques in his own pursuits. He was a keen observer who wrote excellent descriptions of plants. In his two main books, one dealing with plant structures and the second with their functions (physiology), he described over five hundred plant species. His writings influenced botanists over several centuries. Theophrastus was the first to establish a relationship between the structure of flowers and the resulting fruits of plants, but his main theory distinguished between *monocotyledon* and *dicotyledon* seeds. After examining grass and wheat seeds and noticing they had only one seed "coat," he classified them as monocotyledons, while bean seeds, having two seed "coats," were classed as dicotyledons. Cotyledons are the first shoots of the new plant arising from the germinating seed; thus he considered them as "coats" or "covers." He described the differences between flowering plants (angiosperms) and cone-bearing plants (gymnosperms). He coined many new terms and names for plants and their parts and thus is considered by many biologists as the father of botany.

See also Aristotle; Linnaeus

THEORELL'S THEORY OF ENZYME ACTION: Biochemistry: *Axel Hugo Theodor Theorell* (1903–1982), Sweden. Hugo Theorell was awarded the 1955 Nobel Prize in Physiology or Medicine.

The oxidation of the ADH (alcohol dehydrogenases) enzyme is responsible for breaking down alcohol in the kidneys.

Axel Hugo Theodor Theorell was born in Linköping, Sweden. After finishing secondary school in Linköping, he studied medicine at the Karolinska Institute in

Stockholm where he received his bachelor of medicine degree in 1924 and his medical degree in 1930. At Karolinska his areas of interest were the lipids related to blood plasma. He also worked at the Pasteur Institute in Paris for several months in the mid-1920s where he studied bacteriology. As a result of illness, he abandoned the practice of medicine and accepted a teaching and research job in biochemistry and later became head of the biochemistry department of the Nobel Medical Institute in Stockholm. Later he moved to Theodor Svedberg's Institute of Physical Chemistry in Uppsala, Sweden, where Theorell discovered the properties of crystalline myoglobin. He also discovered a "yellowish" enzyme that he called "lactoflavin" but was later renamed "riboflavin" which is related to vitamin B_2. Later, by using an electrophoresis method, he purified the enzyme and separated the protein part of the pigment from the carrier. After determining that its structure is a lactoflavin phosphoric ester, he named it "flavin mononucleotide" (FMN). In 1941 he and his colleagues developed the dehydrogenizing oxidizing enzyme (ADH), a protein that is found in liver and yeast. They discovered that the enzyme is also responsible for the oxidation of alcohol. This led to a practical test for ethyl alcohol in the liver. After thirty-three years as director of the Nobel Medical Institute, he retired in 1970, while still continuing to be involved in enzyme research.

THOMSON'S ELECTRON THEORY: Physics: *Sir Joseph John Thomson* (1856–1940), England.

> *Rays from a cathode tube can be deflected and measured by using magnetic and electric fields. Thus, cathode rays must be particles smaller than an atom and which carry an electrical charge.*

J. J. Thomson experimented with radiation produced by a cathode ray tube. In 1876 the German physicist Eugen Goldstein tested a Geissler tube, a vessel that enclosed a vacuum and used an internal electrode to study the "flow" of electricity. Previously, several other scientists had observed a faint fluorescence within the tube when an electric current was sent through the internal electrode. Goldstein named the tube he used a *cathode-ray tube* because the glow originated from the negative cathode inside the tube. Contrary to Benjamin Franklin's theory that electricity "flowed" from positive to negative, Goldstein noted that electricity flowed from the negative to positive, while others noted this stream of glowing current could be diverted by a magnetic field. Thomson hypothesized that this beam must be composed of charged particles for it to interact with magnetic fields. In addition, he theorized that these charged particles should also react (be bent) in electric fields as well as magnetic fields. He installed an apparatus that measured the deflection of the cathode's rays by both electric and magnetic fields, which enabled him to determine that the ratio of the rays' electric charge to their mass was high. From earlier experiments on the unitary nature of an electric charge, he assumed that the charge he detected on the cathode rays was of the same unit. Therefore, because the ratio was high, this meant the electric charge (e) was much greater as compared to the mass (m) of these new particles, which must be much less based on the ratio e/m. He also assumed these low mass particles from the rays were parts of atoms, not the whole atom, and that they were about one thousand times less than the mass of the hydrogen atom (one proton). It was later determined that this mass equals 1/1837 of that of a proton.

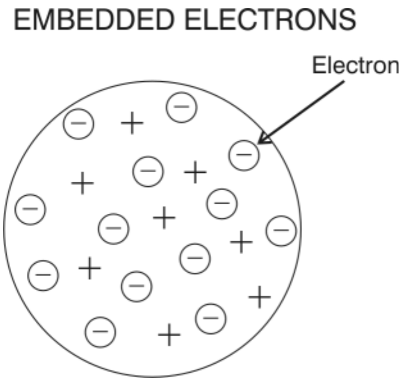

Figure T1. Thomson's early model of the atom was sometimes called the "raisins in pudding" model as he thought the negative electrons were randomly dispersed throughout the atom.

At first Thomson referred to these new particles as *corpuscles*. Later, he named them *electrons* because these new particles carried an electric charge and were detected as originating from the negative electric electrode of the cathode ray tube. Electrons are the fundamental unit of electricity. It is a basic unit. No smaller electrical charge has since been discovered. Thomson designed a model of the atom using electrons embedded in the atom whose sum charge matched the positive protons' sum charge, thus making it a neutral atom. He also investigated the role of the electrons in producing chemical reactions. Sometimes his model is referred to as "berries in muffins," "raisins in pudding," or "the fuzzy atom" because he presumed the electrons were more or less evenly distributed within a pool of positive charged particles throughout the structure of the atom (see Figure T1).

It was later discovered that electrons exist more as electrically charged particles in orbits, shells, or energy levels positioned at a relatively greater distance from the comparatively small, massive, positive, centralized nucleus. This concept of an electrically neutral atom with one or more of its outer electrons joining with those of other atoms is the basis of chemistry and the formation of molecules and compounds. Among other usages, the interaction of magnetic and electric fields on a stream of electrons is used to control the signals that produce the pictures on television receivers and computer monitors.

See also Bohr; Crookes; Faraday; Röentgen; Rutherford; Townsend

TING'S THEORY FOR A NEW PHOTON-LIKE PARTICLE: Physics: *Samuel Chao Chung Ting* (1936–), United States. Samuel Ting shared the 1976 Nobel Prize for Physics with Burton Richter.

> *Bombarding a beryllium target with a stream of positive protons can produce a new subatomic particle with a longer lifetime than expected according to its mass.*

Samuel Ting's parents met as graduate students at the University of Michigan at Ann Arbor, but they returned to China to resume their respective academic careers. While they were on a return visit to Ann Arbor, his mother gave birth prematurely to Samuel, hence his U.S. citizenship. However, at the age of two months, he and his parents returned to a China that was at war. He received his early education as home schooled by his parents and maternal grandmother. Therefore, he did not receive any formal schooling until the age of twelve. Upon returning to the United States in the 1950s, he entered the University of Michigan where he earned a PhD degree in physics in 1962. He worked in various physics laboratories (including CERN in Switzerland and the Deutsches Elektronen-Synchrotron [DESY] in Hamburg, Germany) and has been a professor at Massachusetts Institute of Technology (MIT) since 1969. His research work was more experimental than theoretical, even though his main achievement was a theory based on experimental data (it usually proceeds in the other direction—theories lead to experimental data). He spent most of his time on the physics of quantum electrodynamics and the processes that subatomic particles, such as the photons, undergo as they decay into electrons and muon pairs. His research at the Brookhaven National Laboratory at Long Island, New York, led to the discovery of a new particle that had a lifetime longer than was expected by its heavy mass. About the same time, the American physicist Burton Richter (1931–) at the Stanford Linear Accelerator Center (SLAC) in California independently discovered the same particle. Because Ting called his particle "J" and Richter named his "psi" (Ψ), they combined the two names to call the new particle the JΨ or the J/psi particle. These discoveries were soon confirmed by other high-energy physics laboratories and also have led to the discovery of many more "heavy" subatomic particles.

TISELIUS' HYPOTHESIS FOR PROTEIN ANALYSIS: Chemistry: *Arne Wilhelm Kaurin Tiselius* (1902–1971), Sweden. Arne Tiselius was awarded the 1948 Nobel Prize in Chemistry.

> *Protein molecules carry an electrical charge; thus, it should be possible to separate them by the use of electric fields.*

Arne Tiselius was familiar with electrophoresis, a procedure used to analyze chemical substances by the use of a weak electrical current. Most particles of matter contain a very small electrical charge on their surfaces. If these substances, as solutions, are applied to a special paper strip where one end of the strip is connected to a direct current source with a small negative charge and the other end of the paper is attached to the positive pole, the current will attract or repel the components of the sample substances at different rates. Depending on the size and individual characteristics of the component chemicals in the substance, these individual atoms and molecules will spread out on the strip of paper in very specific patterns, which can then be identified. Tiselius theorized that if this system could be improved to separate the proteins of blood, which also carry a small electrical charge, it might be possible to identify specific components of blood. He developed an improved electrophoresis system consisting of a U tube in which the proteins could be tracked as they separated. The tube could also be "disjoined" to extract specific components of the proteins for analysis. He further designed a lens system for refracting light through the different fractions, enabling a quantitative measurement of the particular protein fraction. Using this system, called the *Tiselius tube*, he identified four major components of blood serum proteins: albumins and the alpha, beta, and gamma globulin proteins. The best known is gamma globulin, whose chemical structure was first detected by American biologist Gerald Maurice Edelman (1929–); it stimulates antibodies in the immune system to protect against several diseases, including hepatitis and AIDS-related infections. Gamma globulin does not protect against the HIV virus.

TODD'S THEORY FOR THE STRUCTURE AND SYNTHESIS OF NUCLEOTIDES, NUCLEOSIDES, AND NUCLEOTIDE CO-ENZYMES: Biochemistry: *Alexander Robertus Todd (Baron of Trumpington)* (1907–1997), Scotland. Alexander Todd was awarded the Nobel Prize for Chemistry in 1957.

Nucleotides, nucleosides, and nucleotide co-enzymes are found in chromosomes (the units of heredity) and cell plasma. They are constructed of three different substances: phosphoric acid, a sugar substance, and a nitrogen heterocyclic base that are all combined in a large macromolecule.

Todd was born outside of Glasgow, Scotland, in 1907 and graduated with a bachelor's degree from the University of Glasgow in 1928. He received his PhD in natural philosophy from the Johann Wolfgang Goethe University of Frankfurt-on-Maine, Germany, in 1931. He also earned another PhD in chemistry from Oxford University in England in 1933. His research on nucleosides led to his investigation of the compounds that formed the units of DNA and RNA. By 1949 he had synthesized adenosine triphosphate (ATP) and flavin adenine dinucleotide (FAD). Some of his major research was related to determining the structure of vitamins to synthesize them. He was the first to determine the structure of vitamin B_{12} and was able to synthesize vitamin B_1 and vitamin E. He also studied the alkaloids contained in marijuana as well as the alkaloids found in plants and insect pigments. Todd was knighted in 1954 and made a lifetime peer in 1962. He was elected president of the Royal Society in 1975. Todd has received numerous other honors, including the Nobel Prize in Chemistry in 1957 for his work on nucleotides and nucleotide co-enzymes.

TOMONAGA'S THEORY OF RELATIVISTIC QUANTUM ELECTRODYNAMICS: Physics: *Sin-Itiro Tomonaga* (1906–1979), Japan. Tomonaga shared the 1965 Nobel Prize in Physics with Richard Feynman and Julian Schwinger.

Quantum mechanics can be applied to subatomic particles by the exchange of another "virtual" particle between two particles, thus developing a quantum field theory consistent with the theory of special relativity.

Sin-Itiro Tomonaga's father was a philosophy professor at Kyoto Imperial University in Japan. After attending the top high school in Tokyo, Sin-Itiro entered Kyoto University, receiving his BA degree in 1929. He spent the rest of his career at Kyoto University, becoming first a professor of physics in 1941 and later in 1956 the president of the university. His research interests were similar to other theoretical physicists in the United States in the area of relativistic quantum field theory of electromagnetism (QED) that was first being investigated as early as 1929. The period of years during World War II prevented the exchange of research ideas between United States and Japanese scientists.

One of the early concepts of light was that it traveled in straight lines, always taking the shortest distance from the source of the light to its reception point. A classical argument was: Because light from a point source travels out in all directions, how does it know where it is going, even if the light's starting and ending positions are known? This is when QED theory was introduced as a possible answer. When light starts from its point of origin, it does not know its end point, but it always takes the shortest path, which is also the quickest path to its end point. QED theory explains this phenomenon by the interaction between light (photons) and charged particles, or just between two charged particles. QED describes the interactions of particles and antiparticles with each other by their exchange of photons, which use a complex set of formulae that have been visualized by the use of Feynman diagrams that assign the best path to all possible paths for the light to take (*see* Feynman). Using QED explains or predicts the probability of what will happen with a high degree of accuracy, making it a very highly accurate and useful physical theory. For instance, according to QED, light can go faster or slower than 186,000 miles per second "c" but on the average will travel at the speed of "c." QED cannot predict exactly what will happen during an experiment, but it can predict the most probable outcome.

See also Dehmelt; Dyson; Feynman; Planck

TONEGAWA'S THEORY OF ANTIBODIES AND THE IMMUNE SYSTEM: Biology: *Susumu Tonegawa* (1939–), Japan/United States. Susumu Tonegawa received the 1987 Nobel Prize for Physiology or Medicine.

> *The B-lymphocyte cells found in the immune system are able to produce billions of different antibody genes, thus providing the organism with protections from a multitude of pathogens.*

The research into the mechanism related to the generation of the diversity of the immune system's production of antibody genes was divided into two opposing camps of theorists. One group was known as the "somaticists" (also known as the *paucigene* group) and the other "germliners" (known as the *multigene* group). As their research progressed, it seemed they both were partially correct. The debate became known as the "generation of diversity" (or GOD). The first group's theory (somaticists) stated that the immune response of the body was dependent on the action of specific cells or antibodies that circulated in the body, whereas the second group's theory (germliners) asserted that there was a specific mechanism (currently unknown) that was responsible for the body's immunological reactions. Louis Pasteur's early work demonstrated how to induce acquired immunity by the use of attenuated pathogens. His theory was that toxins related to specific microorganisms caused infectious diseases and that the immune response was a natural reaction to counter the pathogen. More recent research found that this was not always the case with certain microbacteria, tropical diseases, and parasites where the immune system could not protect the living body. It

> Susumu Tonegawa was born in Nagoya, Japan, in 1939. He attended Kyoto University where he received his bachelor's degree in 1963. He received his doctorate from the University of California, San Diego in 1978. After finishing his PhD, he was employed by the Salk Institute, followed by a period at the Basel Institute for Immunology in Switzerland where he did his major research. In 1981 he became a professor at Massachusetts Institute of Technology (MIT) where he founded and became director of the Picower Institute for Learning and Memory. In the year 2006 he objected to the hiring of a female tenured faculty member for a different neuroscience institute at MIT, namely the McGovern Institute for Brain Research. He ostensibly informed the potential candidate and junior faculty member that he and she would become competitors at MIT. As a result, eleven tenured female MIT colleagues wrote a letter to the university's president, Susan Hockfield, requesting that an investigation be undertaken to review Dr. Tonegawa's alleged unethical conduct. Dr. Hockfield acceded to their request, and an internal MIT investigatory committee was formed, which later found no evidence of gender bias in Dr. Tonegawa's behavior. Nevertheless, he chose to resign his position as director of the Picower Institute at the end of 2006.

was not until the mid-twentieth century when DNA and RNA were discovered and later understood that research confirmed their involvement in the formation of specific antibodies that were developed by genetic mechanisms. Starting in 1976 Tonegawa conducted a series of important experiments that indicated that genetic material rearranges itself to form a multitude of different antibodies. The B-lymphocytes are capable of manufacturing billions of different antibodies that attack specific diseases even though, in humans, this type of cell only carries about one hundred thousand genes in the body's chromosomes.

TORRICELLI'S VACUUM AND THEOREM: Physics: *Evangelista Torricelli* (1608–1647), Italy.

Torricelli's vacuum: *By filling a long glass tube, closed at one end, with mercury and inverting it into a dish of mercury, all but 760 mm of mercury will drain out of the tube, leaving a vacuum in the space above the column of mercury.*

Galileo, who had earlier demonstrated that air had weight, employed Evangelista Torricelli to work for him. Also sometime earlier, Jan Baptista van Helmont claimed air was not an element but rather a mixture of gases. These two concepts were incorporated into the answer as to why a pump could not raise water higher than 30 feet, which was a serious problem when draining mines that were flooded. Torricelli realized it was not the vacuum that "pulled" the water up, but rather the weight of the air (pressure) outside the pump that "pushed" the water up the pipe when low pressure was created inside the pump. In 1643 Torricelli calculated that since mercury weighs about 13.5 times that of water, air should lift quicksilver (mercury) only about 1/13.5 times as high as water. He tested this concept by filling a glass tube, closed at one end with mercury and then inverting the tube into a dish filled with more mercury. He removed the cork from end of the tube immersed in the dish of mercury, allowing the mercury in the vertical tube to settle as gravity pulled it down into the pool of mercury. Torricelli theorized that all the mercury in the tube would not exit the tube and end up in the dish of mercury because the weight of the mercury in the tube was the same weight as air outside the tube. The mercury in the glass tube maintained a height of about 760 millimeters (see Figure T2).

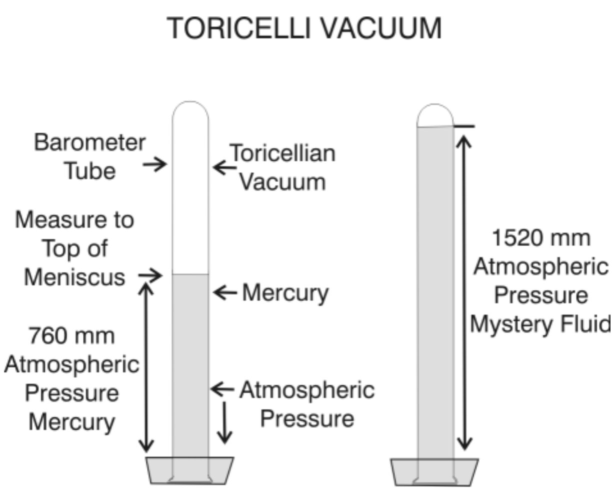

Figure T2. Torricelli's experiment demonstrated that the weight of air exerted pressure on the mercury in the dish, and it disproved the idea that the vacuum at the top of his closed tube "pulled" the mercury up the supporting column of mercury. This was the forerunner of the modern barometer.

The vacuum created over the mercury in the closed end of the tube was named the *Torricellian vacuum* or *torr*, in Torricelli's honor. One torr equals 1 millimeter of mercury (760 torr = 760 mm Hg = 1 atm or atmospheric pressure) (see Figure T3).

After viewing the column of mercury for a few days, Torricelli noticed the

PRESSURE UNITS AND VALUES
FOR STANDARD ATMOSPHERIC PRESSURES

Pressure Units	Abbreviation	Standard
Atmosphere	atm	1.00
Millimeters of Mercury	mm Hg	760
Inches of Mercury	in Hg	29.92
Pounds per Square Inch	psi	14.70
Newtons per Square Meter = Pascal	N/m^2 = Pa	101,300
Millibar	Mb	1,012.3

Figure T3. A table of the various units used to express standard atmospheric pressure.

height of the column varied slightly. He related this to changes in the weight of the air outside the tube of mercury caused by changes in the pressure (weight) of the air at the surface of Earth. This discovery was an unintended consequence of the search for a more efficient water pump, resulting in an instrument (the barometer) that could accurately measure air pressure.

See also Galileo.

Torricelli's theorem: *The flow of a fluid through an opening in a standing pipe is proportional to the square root of the height of the liquid.*

Evangelista Torricelli's experience with the limitations of conventional water pumps and his concept of air pressure as the force that raises the water in "suction" pumps enabled him to develop his theorem. He observed that water escaping through holes at different heights in a standing pipe or container also escaped at different rates of flow. Being a mathematician, he believed there existed, and therefore calculated, a definite square root relationship between the height (depth) of the water and the rate of flow of water from the openings. His theorem is an important concept for industries that handle various types of fluids because the rate of flow as related to the height of the source of the fluid can be measured. This principle is used in elevated community water storage tanks, where pipes carry water under pressure created by the height of the water in the tanks.

See also Galileo

TOWNES' THEORY FOR AMPLIFYING ELECTROMAGNETIC WAVES: Physics: *Charles Hard Townes* (1915–), United States. Charles Townes shared the 1964 Nobel Prize for Physics with Nicolai G. Basov and Aleksandr M. Prokhorov.

> *Molecules that exist in discrete energy states and absorb discrete frequencies of electromagnetic energy will emit photons of the same frequency.*

Albert Einstein pointed out that if an electromagnetic photon of a specific frequency struck a molecule that was in a high-energy state, the molecule would proceed to a lower-energy state while emitting a photon of the same wavelength as the one striking the molecule. Charles Townes realized this would produce two electromagnetic photons of the same frequency, which then could strike other high-energy molecules to produce more photons, resulting in a type of "chain reaction" that would produce a multitude of photons of the same wavelength and frequency. The consequence would be a flood of monochromatic (one-color) single-wavelength photons of the spectrum, all proceeding as coherent radiation (in the same direction). Townes demonstrated this theory by sending small amounts of microwave photons of a given frequency into energized ammonia molecules. The energized molecules had previously been produced by intense broadband irradiation. The microwave photons caused these molecules to drop back to their original energy level, producing new microwave photons. The result greatly amplified the original weak microwave radiation, which resulted in a flood of coherent electromagnetic radiation called the microwave amplification by stimulated emission of radiation (maser). In 1958 Townes proposed this process could be applied to any wavelength within the electromagnetic spectrum. The concept was later improved by using just the section of the electromagnetic spectrum representing visible light, first called the "optical maser" and later named the light amplification stimulated emission of radiation (laser).

See also Turner

TOWNSEND'S THEORY OF COLLISION IONIZATION: Physics: *Sir John Sealy Edward Townsend* (1868–1957), Ireland.

As an electric current passes through gas, some molecules become ionized; they then collide with and ionize other molecules, thus multiplying the original charge.

Sir John Townsend followed up on J.J. Thomson's discovery of the electron, at which time Thomson estimated the electron to be about 1/1000 the weight of the hydrogen nucleus, later revised to 1/1837 the mass of the proton. Thomson also determined that the electron carried the basic negative charge. Townsend calculated the amount of strength of this negative charge by forming a charged cloud of water droplets and measuring the rate of fall of the charged particles as they passed a source of electricity.

Townsend's "collision" theory answered the question of how an electric current could pass through a gas that supposedly had a weak electric field. The explanation was that as the current's electrons passed through the gas, some of the gas molecules became ionized (each gas molecule carried a charge) in the electric field. This created collisions with other gas molecules, which then became ionized, and so on, until an "avalanche" or multiplication of electrons proceeded through the gas despite the weakness of the original electric field. This theory is important in the fields of electronics and communications, where electrons cascade through multiplier tubes used to measure the radiation tracks of subatomic particles.

See also Millikan; Thomson

TURING'S THEORY FOR TESTING COMPUTER INTELLIGENCE: Mathematics: *Alan Mathison Turing* (1912–1954), England.

Because the brain is computable, it must be possible to program computers to acquire human intelligence and devise tests that will verify computer intelligence.

In 1937 Alan Turing designed a computing device called the Turing machine that was connected to several devices including an input device, a long-tape operating program divided into sections, a printer, and a correcting device. The machine had five symbols programmed to control the machine, similar to the operating systems of modern desktop computers and which could be used to make mathematical calculations. After World War II Turing developed several types of computers. He named one the automatic computing engine (ACE) and the other Manchester automatic digital machine (MADAM). By 1950 he argued that a computer could be designed to imitate human intelligence. He then proceeded to design a computer test to prove this concept. The test was based on his idea called an "imitation game," later called the *Turing test*. The Turing test required an interrogator to ask one person and a computer (the interrogator could see neither the computer nor another person) a question that could be answered by typing out a textual answer. Turing claimed that if the interrogator was unable to judge which answer came from the human and which from the computer, then computer intelligence was proven. A similar test is used today to determine if an artificial intelligence (AI) computer program can really imitate human intelligence or "think" (so far, modern computers are only partially successful in imitating the human brain). Alan Turing made distinctions between computer intelligence (AI) and thinking, emotions, and other human attributes.

See also Babbage

> Aside from his contributions to the field of artificial intelligence and computer science, there is another, but less well known, aspect to Alan Turing's short career. During and following World War II, as well as during the period of the cold war in Europe, only a few of Turing's friends knew of his homosexuality. Even so, this fact excluded him from many cooperative sensitive research projects with the United States. At that time, the societies of Great Britain and the United States regarded homosexuals as security risks. In 1952 Turing had an affair with a young man who stole some of Turing's belongings. Turing reported the theft to the police who then arrested Turing. He was given the choice of going to jail for gross indecency or agreeing to probation for one year while undergoing hormone (estrogen) treatment, which was intended to neutralize his libido. At first, Turing tolerated the treatment, but as time went on, he became despondent and eventually took his own life by eating an apple that was laced with cyanide poison. To make the suicide look more like an accident (for his mother's sake), he left the apple by the side of his bed.

TURNER'S THEORY FOR MEASURING OUTER ENERGY LEVELS OF MOLECULES: Chemistry: *David Warren Turner* (1927–1990), England.

The energies of outer electrons ejected from ionized gas atoms or molecules can be measured by deflecting these electrons with an electrostatic charge.

David Turner devised a technique that used a narrow beam of monochromatic ultraviolet radiation (maser) to eject outer electrons from ionized atoms and molecules of gas. The energies of these ejected electrons can then be measured by their degree of deflection as they pass through an electrostatic field. This procedure is known as *molecular photoelectron spectroscopy*. Applying his theory, he assisted in developing a microscope that uses X-rays to "kick" out electrons from the sample, thus measuring characteristics of the sample based on the degree of deflection.

See also Townes

TYNDALL'S THEORY FOR THE TRANSMISSION OF LIGHT THROUGH GASES: Physics: *John Tyndall* (1820–1893), England.

Light passing through a clear solution of dissolved substances is not scattered, while light passing through cloudy water containing large molecules and clusters of molecules (colloids) will be scattered.

John Tyndall, experimenting with the transmission of radiant heat through different types of gases and vapors, measured the absorption and spreading out of the radiation through these gases. In 1859 he studied the effects on light when it passed through various liquids and gases and noted the degree of scattering in the path of the light. This scattering was named the *Tyndall effect*, after his theory that particles in the path of the light cause the scattering that renders the light beam visible. Nephelometry, a field of physical chemistry that examines the scattering properties of small particles in air, is similar to the Tyndall effect. The scattering of the beam of light off minute particles suspended in air is more pronounced and effective when shorter-wavelength ultraviolet radiation is used. Tyndall used this effect to explain why the sky is blue overhead and why sunsets appear red. This occurs because sunlight passes through a greater number of dust particles, filtering out the ultraviolet light, allowing the longer wavelengths of light (orange to red) to be seen on Earth.

Tyndall is credited with first explaining the greenhouse climate effect as being a natural phenomenon. He also measured the air pollution in London using the scattering of infrared light. He was among the first to determine that the dust in the atmosphere contains microorganisms, as well as identifying the ozone molecule as a cluster of three oxygen atoms, not the normal two-atom molecule of oxygen. Tyndall is also credited with many inventions, including the fireman's respirator, an improved foghorn, and the gastroscope that enabled physicians to observe the inside of patients' stomachs without surgery. He made studies that led to improved knowledge of thermodynamics, solar energy, the transmission of light in space, and the structure of the Earth's atmosphere. He is thought of as the father of science education. He conducted many popular and exciting science demonstrations and was responsible for the teaching of the physical sciences in public schools and universities.

See also Ramsay

U

UHLENBECK'S THEORY OF ELECTRON SPIN: Physics: *George Eugene Uhlenbeck* (1900–1988), Netherlands and United States.

A basic property of an electron is its spin around an axis that results in self-induced angular momentum associated with its magnetic dipole moment.

In 1974 George Uhlenbeck, in cooperation with the Dutch-American physicist Samuel Goudsmit (1902–1978), observed the spectra anomalies known as the Zeeman effect (*see* Zeeman) in the spectral lines of X-rays. The quantum number (s) is always $1/2$. The spin of angular momentum of the electron is related to its spin around its axis and is not to be confused with the orbital angular momentum of an electron as it moves in its orbit around the nucleus. This phenomenon cannot be determined by using methods related to classical physics. Rather, the atomic beam method of spectroscopy gives greater precision in the measurement of the frequencies of spectral lines and thus provides greater sensitivity to the factors affecting the magnetic moment of the electron.

George Uhlenbeck's relatives, although of German origin, lived in the Dutch colonies. His father was born in Java in the Dutch East Indies (now called Indonesia) and served in the Dutch East Indian Army. George was born in Batavia, now known as Jakarta in Indonesia. When he was six years old, George's family moved to the Netherlands where he attended elementary, high school, and the University of Leiden. He received his PhD in physics in 1927, the same year in which he emigrated to the United States. He was appointed professor of theoretical physics at the University of Michigan, followed by a position at Columbia University in New York. During World War II he worked on a team out of Massachusetts Institute of Technology (MIT) who were developing radar. In 1960 he moved to Rockefeller Medical Research Center (now Rockefeller University) in New York where he remained until he retired in 1974.

His main interests were atomic structure and the kinetic theory of matter, and his aim was to understand the relationship between physics at the atomic level as well as at the macroscopic level. His students considered him an excellent teacher who was well organized and who made clear the elegant structure of statistical mechanics based on the past work of Maxwell, Boltzmann, Gibbs, and others. He received many awards during and after his career and was responsible for educating several generations of students in the modern esoteric field of statistical mechanics.

See also Boltzmann; Gibbs; Maxwell

ULAM'S "MONTE CARLO" SYSTEM: Mathematics: *Stanislaw Marcin Ulam* (1909–1984), United States.

> *It is possible to obtain a probabilistic solution to complex mathematical problems by using statistical sampling techniques.*

In the early 1940s, Stanislaw Ulam, a Polish Jewish mathematician who was born in Galicia (formerly Austria, now the Ukraine), was asked by the Los Alamos, New Mexico, nuclear development project administrators to develop a mathematical theory for nuclear reactions as applied to nuclear weapons. Before the days of analytical and digital computers, mathematically gifted people performed the tedious mathematical computing tasks and were called *computers*. Ulam's wife, Françoise, was a computer who assisted him in this task. Rather than tracking every uranium or plutonium atom in the atomic bomb models that were being devised by physicists (an impossible task), Ulam used statistical methods to simulate behaviors of individual nuclei in the reaction. He selected, at random, variables of the possible interactions of the nuclei, computed possible outcomes, and analyzed the results using probability statistics. Because his system was based on the *odds* as related to the probabilities of gambling odds, his method became known as *Monte Carlo statistics*, named after the famous gambling casino in Monaco. Ulam's Monte Carlo system of statistical probabilities is employed in many fields other than nuclear energy and has proven a valuable addition to our understanding of several biological processes, including life. In the late 1940s Ulam was involved with Edward Teller and others in the development of the hydrogen (thermonuclear) bomb. Ulam developed the mathematics that ensured success for the final design of the fusion H-bomb, which used a fission A-bomb as the "trigger" to provide the heat, the X-rays, and the pressure required to accomplish the thermonuclear reaction required for the H-bomb. Teller revised Ulam's concept to "focus" the X-rays produced by the A-bomb to trigger the fusion reaction.

See also Teller

UREY'S GASEOUS DIFFUSION AND ORIGIN-OF-LIFE THEORIES: Chemistry: *Harold Clayton Urey* (1893–1981), United States. Harold Urey was awarded the 1934 Nobel Prize for Chemistry.

Urey's theory of gaseous diffusion: *Isotopes of an element in the gaseous state can be separated according to their different atomic weights.*

In 1932 Harold Urey was the first to discover and isolate deuterium (heavy hydrogen) from heavy water (D_2O). He knew liquid heavy hydrogen evaporated at a slower rate than did ordinary liquid hydrogen because regular hydrogen's nuclei are composed of just a single proton, whereas heavy hydrogen's nuclei contain one proton plus one neutron. Deuterium still has an atomic charge (atomic number) of +1, but an atomic weight of 2 (*see* Figure O1 under Oliphant). Using this concept, Urey distilled several liters of liquid hydrogen to about 1 cubic centimeter of deuterium whose existence was confirmed by spectroscopic analysis. Again, using the same principle, he separated the isotopes of uranium-235 (U-235) from uranium-238 (U-238) by converting regular U-238 into a gas and "filtering" it in such a manner that the lighter, unstable U-235 was collected. The isotope U-235, when reaching a critical mass, can be used in a self-sustaining chain reaction. In the early 1940s U-235 was used in the first A-bomb tested in White Sands, New Mexico. The same gaseous diffusion process, based on isotopes of radioactive elements having different atomic weights, was used to separate the isotopes of plutonium, used in the second A-bomb dropped in Japan in 1945. At the end of World War II, Urey's mass production of deuterium made possible the development of the hydrogen fusion bomb (*see also* Fermi; Teller; Ulam).

Urey's theory for the origin of life: *If the right mix of organic molecules existed on primitive Earth, an energy input (lightning, geothermal, or ultraviolet) may have brought life from this "soup."*

Harold Urey and others believed life began on Earth some three to four billion years ago, which is approximately one or two billion years after Earth was formed. These figures are today's best estimates based on fossil and cosmological research. Disagreement still exists as to the source of the organic chemicals that first self-assembled to produce organic polymers and later cells. One possibility being revived is that bacteria and microorganisms arrived on Earth from comet and meteor ice and dust. Urey, along with his graduate student, Stanley Miller, set up an experiment to determine if several chemicals assumed to be on the **prebiotic** Earth could, under laboratory conditions, be converted into organic polymers, which might, under ideal conditions, self-organize into primitive life forms. Urey and Miller formed an atmosphere of methane (CH_4), hydrogen (H_2), ammonia (NH_3), and water (H_2O) in an enclosed glass flask that could be heated. The hot evaporated gases were collected in another flask and exposed to an electric spark between two tungsten electrodes. Following this, the gases were cooled and condensed back to a liquid. They actually produced over twenty-five amino acids, some purines, and other large organic molecules, but no evidence of life itself. An important part of the experiment was the formation of amino acids that combine with some ease to form complex proteins, which are essential for life. Urey's and Miller's work led to the idea that there are at least four stages for chemical evolution of life on Earth: 1) There is a nonbiological synthesis of simple organic molecules, 2) followed by the molecules forming more complex polymers (chains), 3) which form into pre- or probiological "clumps" or simple cells, and 4) some of the first organic substances are primitive RNA followed by DNA, which has the capability to pass on the chemical and living nature of cells from one generation to the next.

See also Crick; Darwin; Miller; Pasteur; Redi; Watson (James)

V

VAN ALLEN RADIATION BELTS: Physics: *James Alfred Van Allen* (1914–2006), United States.

Earth's magnetic field should react with and trap high-speed charged particles originating from space into a concentrated zone above Earth's atmosphere.

James Van Allen first used high-altitude balloons to study cosmic rays, which are high-energy particles (mostly protons) from space that constantly penetrate Earth. Three scientists—S. Fred Singer (1924–) from the University of Maryland, Paul Kellogg (dates unknown) from the University of Minnesota, and Sergei N. Vernov (1910–1982) of the Soviet Union—first proposed the idea that radiation from space surrounded Earth. These energetic particles from the lower altitudes were confirmed by sending photographic film into space in weather-sounding rockets. In 1958 the United States sent its first satellite, *Explorer I,* which weighed thirty-one pounds, into orbit by using a captured German V-2 rocket. Its purpose was to detect high-energy particles in near space. It found many particles at altitudes between 200 and 300 miles but, surprisingly, none were recorded above that region. James Van Allen theorized that this low-radiation "belt" was due to Earth's magnetism, and the reason particles were not detected at higher altitudes was that the radiation counters in the rockets were "jammed" by overwhelming masses of radiation and particles. In 1958, *Explorer IV* was launched containing a radiation counter surrounded by a lead shield that filtered out much of this radiation, thus providing a more accurate count. Additionally, the shielded instruments recorded an increasing amount of high-energy radiation above 300 miles. After World War II the Soviet Union and the United States exploded small atomic bombs in space to track the neutrons and energetic particles that were released. The United States also exploded three small nuclear bombs 300 miles above the South Atlantic to produce energetic particles in the upper atmosphere, which could then be detected and studied. Some radiation and particles from these nuclear explosions in space persisted for several weeks to several years and were strong enough to disable a number of satellites.

By 1967, this practice of detonating nuclear bombs in space was banned worldwide. Van Allen theorized that high-altitude radiation composed of charged particles was concentrated in areas or "belts" trapped by the magnetosphere, which rotates with Earth's magnetic axis. He based his theory on the concept that Earth's magnetic field extends far out into space, and these particles followed the magnetic field as evidenced by their alignment with the poles of this field. This region of concentrated radiation or "belt" was first called the *Van Allen belt*. However, when it was discovered there was more than one radiation belt, the name was changed to the *magnetosphere*. The *inner radiation belt*, the one detected by the Geiger counters used by Van Allen, is a rather compact area of particles in the general magnetosphere region over the equator. This belt is the result of cosmic radiation. Later, an outer radiation belt was discovered, which is composed of "plasma" of energetic charged particles trapped in Earth's magnetosphere at a higher altitude and responsible for magnetic storms on Earth. This magnetosphere phenomenon was later confirmed for other planets as well.

VAN DE GRAAFF'S CONCEPT OF PRODUCING HIGH VOLTAGE: Physics: *Robert Jemison Van de Graaff* (1901–1967), United States.

High voltages can be produced and sustained by electrostatic generators.

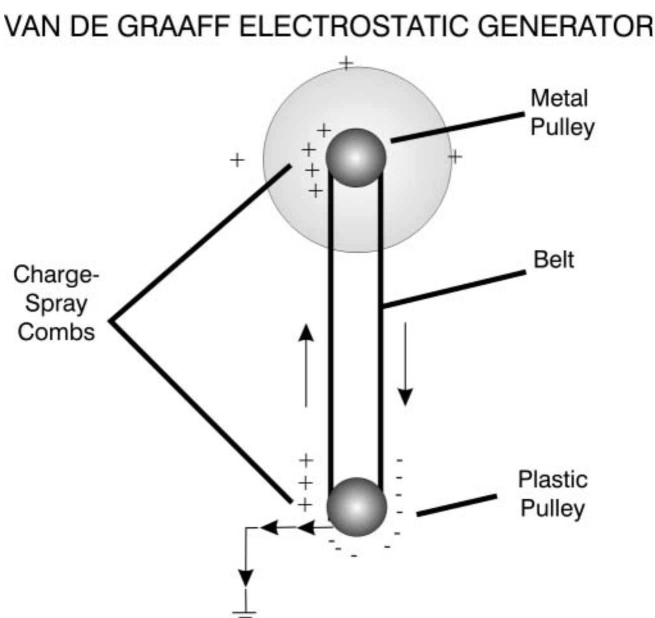

Figure V1. The Van de Graaff electrostatic generator produces an electrical charge from the ground and transfers it by the belt to the metal sphere, where it can be used as an electron source for a variety of research applications.

Robert Van de Graaff was cognizant of the need to produce very high voltages to accelerate subatomic particles, making them useful as "bullets" to bombard the nuclei of elements to produce isotopes and nuclear changes. Regular **AC** and **DC** generators and dynamos were incapable of producing voltages in the million-volt ranges that nuclear physicists needed to create new, heavier elements as well as basic subnuclear particles. Older type "wheel-and-brush" static electricity machines were developed soon after it was learned that static electricity could be stored in a **Leyden jar** by rubbing glass or rosin with silk or wool. These machines created a spark across an inch or two in dry air. In 1931 Van de Graaff devised an improved model that used a hollow sphere with a rotating insulated rubberized belt to transfer the charge to the surface of the metal sphere (*see* Figure V1).

Although his first models generated up to 100,000 volts with just a fraction of amperes (current), they were inadequate for use as particle accelerators. Van de Graaff's later models were enclosed in a tank with the insulated belt extracting negative ions from the ground (Earth), where they were stripped of their electrons and thus became positive ions. As the charges return to the grounding terminal, the negative ions are accelerated to achieve up to 10 million volts or 10 MeV of energy (but with very low amperes). Recently, even higher voltages have been achieved. This high voltage can accelerate charged particles (electrons and positrons) to very high energies, which can then be used as "bullets" to bombard target nuclei. Two of the first applications of this very high energy were the exploration of the nature of uranium nuclei fission and the production of high-energy X-rays for medical and industrial use. Van de Graaff generators, when used in combination with other types of particle accelerators, generate the tremendous speeds (energies) of charged particles needed to knock out the many particles from atomic nuclei. Van de Graaff generators also produce high-energy X-rays to detect flaws in machinery and small cracks in airplane structures, and to inspect the interiors of explosive weapons.

See also Tesla

VAN DER MEER'S THEORY OF PARTICLES TO CONFIRM THE "WEAK FORCE": Physics: *Simon Van der Meer* (1925–), Netherlands. Simon Van der Meer shared the 1984 Nobel Prize for Physics with Carlo Rubbia.

The unification of the electromagnetic and weak forces requires the existence of three heavy particles—one negative, one positive, and one neutral.

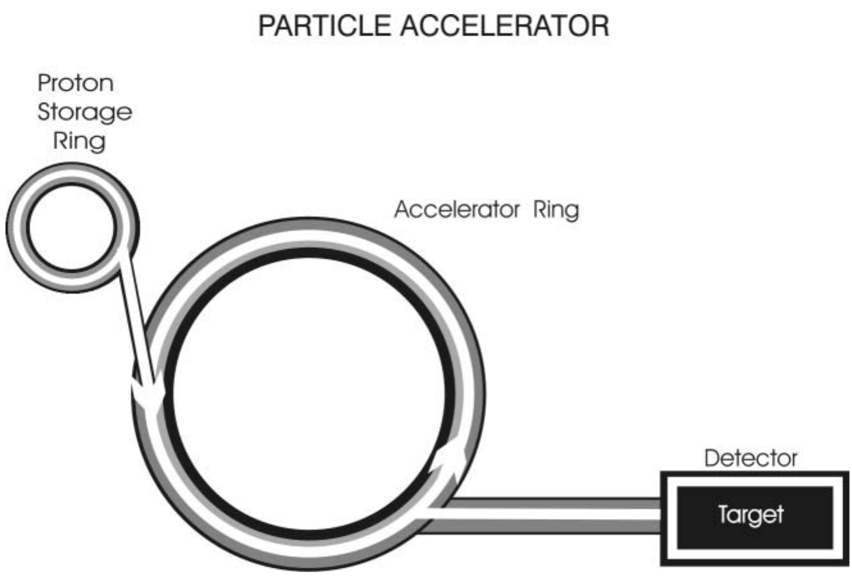

Figure V2. Particle accelerators are used to analyze and understand the nature of matter and energy. Subatomic particles are accelerated around the ring by electromagnetic forces until they approach the speed of light, which is required to smash into targets that break up into smaller particles, as well as energy that can be recorded and analyzed.

CERN is the main research organization for nuclear and particle research in Europe. It occupies the grounds of former German dairy farms outside Geneva, Switzerland, and consists of several dozen buildings on the border of Switzerland and France. Van der Meer, who confirmed the ''weak force,'' and Carlo Rubbia used the present particle colliders at CERN for their research through the 1990s. Physicists realized that even with as much as they already know about submicroscopic particles of matter and energy, something more fundamental to matter in the universe remains missing. CERN is almost finished constructing the most ambitious research apparatus to conduct experiments to explore particle physics. It is called the Large Hadron Collider referred to as L.H.C., which, as of today, is the only attempt to test theories of ''new physics,'' including the controversial ''string theory.'' String theory claims that the ultimate particle/energy bits of matter consist of ''strings'' of various shapes too small to see that may exist in multiple universes. Also, they might exist beyond the four dimensions we already know and experience, that is, height, width, depth, and time. The L.H.C. is a circular tunnel 17 miles in circumference and 300 feet deep. An elevator is needed to descend to the research level. Once it is operational in late 2008, the first expected experiment will involve a group of scientists analyzing a four-million-megabyte-per-hour flow of data that will attempt to address many unanswered questions in the field of particle physics.

Van der Meer predicted that theoretical particles related to weak interactions were about eighty times as massive as protons, thus requiring a tremendous energy source to produce and detect them. The major obstacle to detecting these particles and confirming the theory of the weak interactions was their theoretical mass. In 1989, Van der Meer and his colleague, Carlo Rubbia, succeeded in generating energies sufficient to produce these massive particles. Arranging for a super-synchrotron (circular particle accelerator) to provide two beams of particles to collide head-on, they accelerated a beam of protons in one direction and a beam of antiprotons in the other (*see* Figure V2).

The result was a collision of particles, each at great energies, detected in the synchrotron's target. This collider concept greatly increased the energy to over 150,000 GeV, which was adequate to produce and detect the three heavy theoretical particles. They were named W^+, W^-, and the neutral Z^0 **bosons**, which coincide with and confirmed the weak interaction now proven by Van der Meer but first suggested by Enrico Fermi. The weak interaction is similar to electromagnetic interactions of particles except the weak interaction involves neutrinos, making it a much weaker force than electromagnetic forces. At the same time weak interactions are much stronger than gravitational interactions on particles. The weak interaction (and related particles) is one of the basic forces of nature, as is the "strong force," which binds neutrons and protons together in atomic nuclei.

See also Fermi; Rubbia

VAN DER WAALS' EQUATION FOR GAS MOLECULES: Physics: *Johannes Diderik Van der Waals* (1837–1923), Netherlands. Johannes Van der Waals was awarded the 1910 Nobel Prize in physics.

Electrostatic forces are responsible for the attraction between gaseous molecules, thus affecting the corresponding relationships between the temperature, pressure, and volume of gases.

The ideal gas law combines the Boyle–Charles gas laws and is limited to gases at "normal" pressures and temperatures. This law is not effective for "real" gases under other than "normal" conditions—very high or low temperatures or pressures. The ideal gas law equation relates the three properties of temperature, pressure, and volume for a chemical gas, $pV = nRT$, under normal conditions (*see* Ideal Gas Law). Johannes Van der Waals related the ideal gas law to the kinetic-molecular theory, which could account more accurately for the behavior of real gases and liquids by considering the attractive forces between molecules as well as their actual (but limited) volumes under other-than-normal conditions. The ideal gas law might be considered the equation of the "first state," whereas Van der Waals' equation is an equation of the "second state," which more accurately relates the behavior of gas molecules to kinetic energy under a variety of corresponding states of temperature, pressure, and volume. Van der Waals' equation is $(p + na/V^2)\ (V - nb) = nRT$. In this equation the *n's* are amounts, *a* and *b* are constants, na/V^2 accommodates the attractive forces between molecules of gases that may be more than zero, and $V - nb$ states the volume of a real gas is never zero, which restricts the gas's molecular motions in its actual volume. The weak electrostatic attractive force between the atoms and molecules of all substances is called the *Van der Waals force*. His equation enabled other scientists to solve the problems of how to liquefy gases found in the atmosphere.

See also Boyle; Charles; Gay-Lussac

VAN'T HOFF'S THEORY OF THREE-DIMENSIONAL ORGANIC COMPOUNDS: Chemistry: *Jacobus Henricus Van't Hoff* (1852–1911), Netherlands. Jacobus Van't Hoff was awarded the first Nobel Prize in Chemistry in 1901.

The three-dimensional symmetrical structure of organic carbon compounds accounts for their optical activity.

Until 1874 molecular structures were depicted as two-dimensional. Also in 1874, Friedrich Kekule proposed his famous structure for the carbon atom as having four electrons oriented to the corners of a square, which explained left- and right-sided isomers of some elements. While contemplating this structure for the carbon atoms, Kekule dreamed of a snake eating its tail (*see* Figure K1 under Kekule). This gave him the insight for forming a ring of carbon atoms to form the benzene molecule. The benzene ring is a molecule that has six carbon atoms, each of which shares its electrons with its neighbors. The problem with his depiction was that the ring was two dimensional, which did not explain how certain molecules (isomers) polarize light in solution. In the same year, Jacobus Van't Hoff recast the organic carbon atom into a tetrahedral three-dimensional structure with the four bonds of the carbon atom pointed toward the vertices of the tetrahedron rather than to the corners of a two-dimensional square (*see* Figure V3).

Van't Hoff's model placed the atom as suspended in the central area of the three-dimensional figure. This was not only a unique insight but explained how some organic isomers are structured and react in solutions. Certain isomers do polarize light in solution; others do not. The difference is in the two- or three-dimensional structures of the molecules. Van't Hoff's theory of asymmetrical three-dimensional optically active carbon (organic) compounds provided the basis for modern stereochemistry (the study of how atoms are arranged [structured] within molecules and how this affects chemical

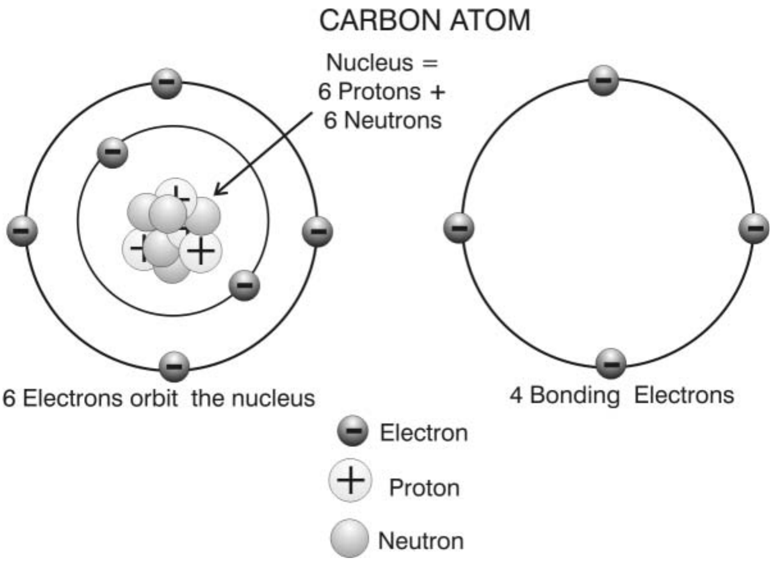

Figure V3. Van't Hoff determined that there are 4 electrons in the outer shell of the carbon atom. The carbon atom's structure with four valence electrons may be thought of as a tetrahedron with four vertices representing the bonding electrons. The tetrahedron has six edges and six line segments to join each pair of vertices. It is a representation of a three-dimensional triangle with the center being the carbon atom. This structure gives the carbon atom its unusual versatility and importance in forming organic and inorganic compounds

reactions). Van't Hoff's theory resulted in his law of chemical dynamics, which is important in the study of osmotic pressure in solutions.

See also Baeyer; Fischer; Kekule; Pasteur; Van der Waals

VAN VLECK'S THEORY OF PARAMAGNETISM: Physics: *John Hasbrouck Van Vleck* (1899–1980), United States. John Van Vleck shared the 1977 Nobel Prize for Physics with Nevill Mott and Philip Anderson.

> *Paramagnetic substances are independently susceptible to magnetic induction according to the temperatures involved.*

John Van Vleck extended the concept of quantum mechanics associated with particles to include not only quantum aspects of waves but also magnetism. There are two basic types of paramagnetism—the first involves electrons and the second involves nuclei of atoms. Atoms of elements that have an odd number of electrons, according to quantum mechanics, cannot have a spin of zero. This results in atoms with a magnetic moment that can be affected by a magnetic field. Examples are atomic and molecular radicals (with a charge). Paramagnetic materials are magnetized parallel to the magnetic field to which they are exposed. In general, they do not become as highly magnetized as do ferromagnetic materials, and they behave differently at very high and very low temperatures. The best examples of paramagnetic materials are the atoms and compounds of the rare earths located within the transition elements of the

Periodic Table of the Chemical Elements. Other examples are free organic radicals, nitric oxide, some low-conducting metals, and molecular oxygen. The effect of temperatures on the quantum nature of paramagnetic materials is known as *Van Vleck paramagnetism*. Paramagnetic materials are used in combination with liquid helium to remove additional heat in attempts to reach absolute zero. First they are magnetized. Then, when the magnetic field is removed, the molecules become randomly disorganized and remove more heat from the helium. A temperature of less than 0.5 kelvin has been achieved.

VESALIUS' THEORIES OF ANATOMY AND PHYSIOLOGY: Biology (Anatomy): *Andreas Vesalius, aka, Andre van Wesel* (1514–1564), Belgium/Flanders.

More accurate anatomical features of human organs can be observed by actually performing surgery on human cadavers rather than using animal bodies.

Andreas Vesalius is rightfully known as the father of modern human anatomy. This is a title he well-deserved because he spent most of his life not only studying the human body, but also making astoundingly accurate drawings of various parts of the anatomy. Many of these drawings are still in use and are highly prized today.

His father Andries van Wesel was the illegitimate son of the Holy Roman Emperor Maximillian's royal physician whose name was Everard van Wesel (dates unknown). In time, Andries became the apothecary to Emperor Maximillian I of Habsburg (1459–1519) while young Andre was being educated to follow in his father's footsteps. Vesalius entered the University of Leuven in Belgium in 1528, majoring in the arts, but soon decided to pursue a career in medicine at the University of Paris. While at Paris, he studied the theories of several well-known physicians, including Galen and the French anatomist Jacobus Sylvius (1478–1555). Due to the war between the Holy Roman Empire and France, he was forced to return to Leuven to

Vesalius was one of the first to use cadavers of executed criminals to perfect his knowledge of anatomy. Because refrigeration was not available in those days, he would work day and night to complete the job before the corpse putrefied. Because Leonardo da Vinci's anatomical drawings had not yet been published, Vesalius was not able to benefit from them. Even so, Vesalius' drawings were superb as well as accurate. This caused him a great deal of trouble because they challenged the anatomical misconceptions of Galen. One reason for the discrepancy was that Galen used animals (mainly pigs) for his dissections and Vesalius used humans. Vesalius' anatomical drawings and his accurate descriptions that appeared in his publications were the beginning of the end of the fifteen-hundred-year long "tyranny of Galen" that lasted well into the Renaissance period. Even so, Vesalius could not entirely break away from Galen's hold as the last word in human anatomy. The excuse that some physicians used for the discrepancies between the Galen and the Vesalius publications and drawings of the human body was that the body went through a series of dramatic changes in structure during this short period of history. The argument became more serious after Vesalius pointed out more errors by Galen. For instance, Galen believed that there were microscopic holes in the tissue (septum) that separated the heart's left and right ventricles that allowed the passage of blood from one side to the other. And even though he knew better, Vesalius accepted Galen's position. In Vesalius' seven-volume book *De Humani Corporis Fabrica* (usually referred to as *De Fabrica*) published in 1543, the author made many more corrections to Galen's teachings. Many physicians of the day criticized Vesalius' books to the point that he burned his remaining books as well as his unpublished material. It was not until after his death that Vesalius' work was recognized and accepted.

complete his studies. After an argument with one of his professors, he accepted the chair of Surgery and Anatomy at the University of Padua in Italy. For this time in history, his methods of teaching anatomy were most unusual. He performed his own surgery with the students gathered around him so they could better see what was being discussed. Generally, older instructors had assistants do the surgery while the professor read from out-of-date textbooks. In addition, they accepted the writings of Galen and others as correct with no effort to verify these statements with the facts before their eyes. Vesalius used dissection as a major hands-on teaching tool. He believed that direct observation was the only reliable source of information. Vesalius maintained a file of his superb drawings as large illustrated anatomical teaching tools for his students. When he found that they were being copied, he decided to publish them in 1538. These drawings were used in a debate as to the best method of "letting" blood to be used as a treatment for many illnesses. The ancient method advocated by Galen was to draw the blood from a site near the illness (which Vesalius supported); the other method, which was preferred by ancient Muslim physicians, accepted that the blood could be drawn from a more distant site and be just as effective. Vesalius' diagrams won the argument. He also rectified several other incorrect assumptions, for example, that the heart has four chambers—not two, that the liver has two lobes, that blood does not pass through the septum of the heart, and that blood vessels do not originate in the liver, but rather in the heart.

See also Galen

VIRCHOW'S CELL PATHOLOGY THEORY: Biology: *Rudolf Carl Virchow* (1821–1902), Germany.

Cells are the "seat" of disease, thus diseased cells arise from other diseased cells.

Rudolf Virchow accepted the concept first stated by William Harvey and the Scottish anatomist John Goodsir (1814–1867) that *cells are derived from preexisting cells*. Virchow's contribution to the field of pathology was his belief that disease is a pathological state of cells based on observations that abnormal cells found in particular diseases arose from normal healthy cells. He believed living cells could originate only from living matter. Virchow noted this was not a rapid process. Rather, once disease infected just one or only a few cells, these cells infected other healthy cells over a period of time. Some years later, the germ theory of disease, which he rejected, made Virchow's theory less important because this new theory provided a more rational explanation for disease. Even so, Virchow is regarded as the father of pathology.

See also Harvey; Lister; Pasteur; Schleiden; Schwann

VOLTA'S CONCEPT OF AN ELECTRIC CURRENT: Physics: *Count Alessandro Giuseppe Antonio Anastasio Volta* (1745–1827), Italy.

A flowing electric current is not dependent on animal tissue and can be produced with chemicals.

Count Alessandro Volta was acquainted with Benjamin Franklin's single-fluid theory of electricity and the French chemist Charles du Fay's (1689–1739) two-fluid electricity. He also knew of Luigi Galvani's belief that moist animal tissue was required to produce a continuous flow of electricity. Volta decided these theories had weaknesses and that a combination of the correct chemicals and materials could produce an electric current. In particular, he believed that dissimilar metals, not the animal tissue of Galvani's frog experiment, generated Galvani's electricity. In 1800, Volta separated alternating sheets of zinc and silver with sheets of cardboard soaked in concentrated saltwater, which acted as the electrolyte. This was called a *voltaic pile* and resulted in a revolution in the source and use of small amounts of electricity. His "pile" enabled others to develop mechanical clappers on electric bells, the telegraph, modern dry and wet cells, and batteries of cells, which are a combination of a group of cells connected in series or parallel. The unit of electric potential (force or pressure of the current) is named after Count Volta (volts = amps × ohms).

See also Faraday; Franklin (Benjamin); Galvani; Henry; Ohm

VON LAUE'S THEORY FOR THE DIFFRACTION OF X-RAYS IN CRYSTALS: Physics: *Max Theodor Felix Von Laue* (1879–1960), Germany. Max Von Laue was awarded the 1914 Nobel Prize in Physics.

> *If the wavelength of X-rays is similar to the space between atoms in crystals, X-rays passing through a crystal composed of atoms in a lattice arrangement should produce a diffraction pattern.*

It was known for some time that X-rays consist of electromagnetic waves similar to light and that electromagnetic wavelengths of X-rays are much shorter than waves of light. Max Von Laue was aware of this fact, even though it was not yet established that X-rays were one form of radiation exhibited in the electromagnetic spectrum. He also knew of the research indicating that the atoms in crystals may be arranged in very regular patterns, similar to a lattice structure, where they were lined up in rows. His theory stated that if the small crest-to-crest distance of the short wavelengths of X-rays were the same as the small distances between the atoms that make up crystalline substances, then diffraction of the X-ray beams should occur. He proceeded to "shoot" X-rays through crystals and record the diffracted beams on photographic plates. His first attempts produced rather blurred but nonetheless expected diffraction patterns, thus proving his theory. Von Laue's theory established that though X-rays were part of the electromagnetic spectrum, they are of a much shorter wavelength than visible light. Just as important, his work demonstrated that atoms in organic crystals and some organic substances are arranged in a symmetrical and regular order. His X-ray techniques aided researchers in decoding the structure of DNA, and his work with crystals ushered in the field of solid-state physics, leading to the development of modern electronics, including semiconductor microchips and computers.

See also Crick; Franklin (Rosalind); Maxwell; Röentgen

VON NEUMANN'S THEORY OF AUTOMATA: Mathematics: *John von Neumann* (1903–1957), United States.

Von Neumann's theory of "artificial automata" (computers) might be expressed as: *(a set of inputs) to → (a set of internal states) yields → (a set of outputs).*

After emigrating to the United States from Germany in 1930, John von Neumann attempted to solve complicated mathematical problems related to the development of the atomic bomb, hydrodynamics of submarines, missiles, weather predictions, and military strategy. Much of this work required deciphering complicated nonlinear equations, which proved to be difficult and time-consuming. Von Neumann developed a systematic mathematical theory in logic that he called "automata," which he reasoned would help develop a better understanding of natural systems and what he called "artificial automata" (computers). The automata theory relates to three states of a system that involve three sets: namely, 1) the input, 2) the current internal state of the system, and 3) the output from the system. These operations can be thought of as three sets of information and two functions. In essence, this is von Neumann's design for a computer, which is also the basic logic for current computers: the program (input), the operating system (internal state), and the data produced (output). In 1952 von Neumann developed the Mathematical Analyzer, Numerical Integrator, and Computer (MANIAC), the first modern computer using an internally stored program (operating system). It was a huge machine that filled a room and required extensive cooling to keep the vacuum tubes from overheating. It provided the basic logic (automata) and design for modern computers.

See also Turing

W

WADDINGTON'S THEORY OF GENETIC ASSIMILATION: Biology: *Conrad Hal Waddington* (1905–1975), Scotland.

> *By means of natural selection, acquired characteristics can be inherited genetically and through the process of evolution.*

During Darwin's lifetime, the science of genetics had yet to be developed; therefore the old Lamarckian belief that characteristics acquired after birth could be inherited was still considered viable. Once research and evidence that genes are the carriers of physical characteristics became known, Lamarckism became heresy. Waddington conducted an experiment that he claimed proved his theory of "genetic assimilation" (of acquired characteristics) by exposing the pupae stage of the fruit fly (*Drosophila*) to heat. He noted that a few exposed flies exhibited a different pattern of veins in their wings. Waddington separated and bred these different flies in an attempt to increase their numbers. After repeating selective breeding of flies for several generations, he observed that a large number of offspring manifested this same pattern; thus they seemed to be breeding true. Therefore, Waddington concluded that genetic assimilation of imposed characteristics resulted through the process of natural selection. Most scientists discredited his experiment and theory.

See also Darwin; Lamarck; Lysenko; Wallace; Zuckerandl

WALDEYER-HARTZ NEURON THEORY: Biology: *Heinrich Wilhelm Gottfried von Waldeyer-Hartz* (1836–1921), Germany.

> *The nervous system is composed of individual cells whose fine extensions do not join cells adjacent to them but still communicate with a neighboring cell.*

Heinrich Waldeyer-Hartz studied animal tissue cells and their structures, defining the "colored bodies" in cells as *chromosomes*. He also studied nerve tissue and was the first to realize that nerves are not only composed of cells, just as in other animal tissue, but that the individual nerve cells are not in contact with each other; there is a gap where one nerve cell ends and the next begins. He named these individual nerve cells *neurons*.

See also Dale

WALLACE'S THEORY OF EVOLUTION BY NATURAL SELECTION: Biology: *Alfred Russel Wallace* (1823–1913), England.

The tendency for species to produce variations as they drift from their original types is due to a separation of their ecologies.

In the late 1800s Alfred Wallace, a contemporary of Charles Darwin, collaborated with Darwin on the development of the theory of organic evolution. Wallace proposed his concept, known as the *Wallace line,* where the separation of geographical landmasses results in the development of distinct species. His theory was based on the differences of animal species that he observed in Australia and Asia. Wallace claimed this "line" between species was created by the separation of the two landmasses, which, over a long period of time and many generations, also separated individual species that developed in very different directions due to natural selection created by disparate ecologies. His theory that varieties of a species tend to drift apart indefinitely from the original type is generally accepted today. The study of the geographic distribution of plants and animals is known as biogeography.

See also Darwin; Waddington

WALLACH'S THEORY FOR THE MOLECULAR STRUCTURE OF ORGANIC COMPOUNDS: Chemistry: *Otto Wallach* (1847–1931), Germany. Otto Wallach received the 1910 Nobel Prize in Chemistry.

Pharmaceutical medications as well as the essences of many oils are composed of a variety of related forms of the hydrocarbon molecules.

While studying pharmacology, Otto Wallach removed the essential oils from plants using steam distillation. Many of the resulting organic compounds were used as medicine as well as in the production of perfumes, creams, and flavorings. He theorized that many of these organic substances were chemically related but was unsure of how or why their molecular structures differed. Wallach, however, identified the great variety of a particular group of compounds, all of which possessed the same general formula but with different molecular weights (isomers). One of these, terpene ($C_{10}H_{16}$), is an unsaturated hydrocarbon found in some plants and has a unit structure containing five carbon atoms (C_5). A group of organic compounds similar to terpene that has the same molecular weight but different structures is referred to as an *isoprene*. He expanded this terpene example of a hydrocarbon isoprene with the general formula $(C_5H_8)_n$ to include other hydrocarbon compounds. Wallach also discovered that these molecules could be polymerized to form other higher-molecular-weight molecules, resulting in other larger organic (hydrocarbon) molecules with formulas that are multiples of the basic terpene $C_{10}H_{16}$ formula. Some examples of these isoprenes are camphene, citrine, cinene, eucalyptine, and common terpentine. Wallach's work with the basic structure of various $(C_5H_8)_n$ isoprenes was instrumental in improving and expanding several industries, including pharmaceuticals and perfumes.

See also Kekule; Pauling

WALTON'S CONCEPT FOR TRANSMUTING ATOMIC PARTICLES: Physics: *Ernest Thomas Sinton Walton* (1903–1995), Ireland and England. Ernest Walton shared the 1951 Nobel Prize for Physics with John Cockcroft.

> *See* Cockcroft for details of the theory proposing that accelerated protons split lithium nuclei into alpha particles (e.g., lithium + proton → alpha + alpha + energy).

WATSON–CRICK THEORY OF DNA: Biology: *James Dewey Watson* (1928–), United States. James Watson shared the 1962 Nobel Prize in Physiology or Medicine with Francis Crick and Maurice Wilkins.

> *See* Crick–Watson for details describing their theoretical model of the DNA double-helix molecule.

WATSON'S THEORY OF ELECTRICITY AS A FLUID: Physics: *Sir William Watson* (1715–1787), England.

> *Electricity is an "electrical ether" or single fluid of various densities that is contained in different material bodies.*

William Watson improved the effectiveness of the **Leyden jar** that was independently invented by Dutch scientist Pieter van Musschenbrock (1692–1761) and Prussian scientist Ewald Georg von Kleist (1700–1748) by lining the interior of the glass jar with metal foil. This improved device enabled Watson to store a large charge of static electricity and study the resulting larger electrical discharges, ultimately leading to his belief that electricity is a single "fluid." Watson theorized that different materials contained differing densities of this "electrical **ether**." If the density of two objects was equal, there was no sparking discharge, but if the "fluid" densities were unequal, the one with the greater density would discharge to the object with lesser density, until they were again equal. Although this theory is incorrect, it might be considered a forerunner of the concepts of equilibrium and the conservation of energy, including the concept entropy.

See also Ampère; Faraday; Franklin (Benjamin)

WATSON-WATT'S CONCEPT OF RADAR: Physics: *Sir Robert Alexander Watson-Watt* (1892–1973), England.

> *The interference in radio reception caused by airplanes flying over transmitting stations can be used to detect approaching aircraft.*

Robert Watson-Watt knew that some radio engineers complained about radio signal interference caused by passing airplanes. In the late 1930s, he theorized that this phenomenon might be used to detect enemy aircraft. In addition to this radio "interference" by aircraft, he based his concept on the results of two other research projects: 1) the use of radio waves to determine the range in miles of different layers of the atmosphere and 2) the use of radio signals to determine the existence and distance of thunderstorms. There were two main problems with using this concept for a reliable aircraft-detecting device at a distance of more than a few miles: 1) the need for a very high-powered transmitter and 2) the fact that only a very small, weak signal was "bounced" back to the receiver. Therefore, the receiver had to be capable of amplifying the signal by many factors greater than what was required for normal radio receivers. Along with scientists and engineers from the United States, he continued to develop a workable system he called *radio detection and ranging* (radar). By late 1938 several radar units were placed on the east coast of England to aid in the detection of approaching German bombers. Since that time, radar units have become much smaller and more sensitive. Radar has found many uses, including handheld units to detect speeding vehicles on roads and highways.

See also Doppler

WEBER'S THEORY OF GRAVITATIONAL WAVES: Physics: *Joseph Weber* (1919–2000), United States.

> *Gravity waves should have the same characteristics of energy and momentum as do electromagnetic waves, and thus be detectable.*

Joseph Weber accepted Einstein's theory of general relativity, which included the concept that any accelerating mass generates gravitational waves as well as electromagnetic waves. Photons of light (electromagnetic radiation) exhibit wave and momentum characteristics; thus electromagnetic radiation must have mass. Weber reasoned that gravity waves should also exhibit momentum and thus be detectable; however, gravitational waves have not been detected because gravity is one of the weakest forces in nature. It may not seem so weak when falling to the ground, even from a low height, but compared to other forces of nature, such as the binding force of nuclear particles or even the forces that forge molecules out of chemical atoms, gravity is not very strong. In the mid-1960s, Weber designed a special barrel-like "antenna" detector that was three feet in diameter, constructed from aluminum and weighing more than three tons. He placed a series of piezoelectric crystals in its interior to detect gravity waves. He figured that any force, no matter how small, would alter the shape of these crystals; if there was even the slightest pressure exerted by an oscillating gravity field, the crystals would convert this distortion to an electric current that could be detected and measured. This instrument was so sensitive that the piezoelectric crystals could detect any deformity in their shape as little as 1/100th the diameter of an atom. To ensure gravity waves were being detected and not some other phenomenon, Weber erected a second detector at some distance from the first so that each antenna detector could be oriented in various directions. After several months, he claimed to have received what are called "coincident readings," meaning that when both cylindrical detectors were oriented toward the center of our galaxy, the same readings were recorded. Weber's results were never duplicated by other scientists despite the thousands of dollars spent on improved detectors. In fact, no "coincident readings" were ever recorded, even when one gravity wave detector was placed on the East Coast and one on the West Coast of the United States. Scientists have not abandoned the theory that gravity waves exist but rather assume they are too weak to detect with current instruments. A more recent experiment "shoots" two laser beams of monochromatic light at each other from a distance of several miles. When the beams collide, they interfere with each other. If gravity waves exist, they may possibly alter the interference pattern and thus be detected. Theoretical physicists predict that sometime in the early twenty-first century, gravitational waves will be detected, a belief based on their confidence in the proven reliability of the theory of general relativity.

See also Einstein; Curies

WEGENER'S THEORY OF CONTINENTAL DRIFT: Geology: *Alfred Lothar Wegener* (1880–1930), Germany.

All land at the surface of Earth was once connected with the configuration of a "supercontinent," which, over time, separated into large sections that drifted apart to form the present continents.

Scientists have long speculated on the shape of the world's landmasses and why this shape changed over eons. Sir Francis Bacon was the first to notice the similarity of the coastlines of eastern South America and western Africa and to suggest that they were once joined. Building on Eduard Suess' theory that western and eastern landmasses were once joined to form the hypothetical continent Gondwanaland, in 1924 Alfred Wegener called his "supercontinent" *Pangaea*, which means, "all-land" or "earth" in Greek (*see* Figure S6 under Suess). Wegener based his theory on four important observations:

1. There is a more accurate "fit" of the edges of the underwater continental shelves of the current continents than there is on the above-water coast lines.
2. Current measurements indicate Greenland is moving westward from the European continent.
3. Earth's crust is composed of a lighter granite-type rock material, which floats on the heavier inner basalt material. Thus, the crust is composed of two layers, and the continents formed of granite "float" over the heavier basalt ocean floor.
4. Although there are significant differences in plant and animal species found on various continents, there are also great similarities of species found on the now-separated continents, indicating these continents were once connected.

At first, many scientists disagreed with Wegener's theory of continental drift. Today it is accepted in an updated version to conform to the new science of plate tectonics.

See also Ewing; Hess (Harry); Suess

WEINBERG'S GRAND UNIFICATION THEORIES: Physics: *Steven Weinberg* (1933–), United States. Steven Weinberg shared the 1979 Nobel Prize in Physics with Sheldon Glashow and Abdus Salam.

Weinberg's theory of the unification of electromagnetic and weak forces: *The interchange of photons and the weak force with the W and Z bosons results in the electroweak force combining with the electromagnetic force.*

Steven Weinberg knew of the dilemma of symmetry relating to photons, which are practically weightless, whereas bosons, which have intrinsic angular momentum, are a bit heavier than positive protons. He explained this conundrum by recounting the outset of the big bang. Weinberg used the idea of spontaneous symmetry breaking (where the symmetry of particles and energy was disturbed—chaos) to illustrate what occurred during the cooling-off period that followed the tremendous temperatures created at the outset of the big bang. This resulted in many fundamental particles assuming very different characteristics, leading to the belief that the current four primary natural forces were combined as one major force at that time. The four natural forces are:

1. *Gravity*. Although gravity is the weakest of these four forces and exhibits only an attractive force and acts over infinite distances, it is the predominant force over the entire universe.
2. The *weak nuclear force* causes the beta (electron) decay of a neutron into a neutrino and electron (neutron → proton + beta + neutrino). It is one of the fundamental interactions of elementary particles (*see* Figure F2 under Fermi). Essentially, it involves leptons and acts over extremely small distances, ranging between 10^{-9} and 10^{-10} cm.
3. The *electromagnetic force* acts on particles with electric charges and holds electrons to their orbits around the nuclei of atoms. It exhibits both attractive and repulsion forces and acts over infinite distances. The electromagnetic interactions are limited to atomic and molecular particles.
4. The *strong nuclear force* is the strongest of these four natural forces. It binds protons and neutrons (and quarks) together by gluons in the nuclei of atoms. It mostly involves hadrons and acts over small distances, ranging from about 10^{-6} to 10^{-9} cm.

Weinberg–Salam greater unified theory: *The four fundamental forces of nature interact to make up all the forces found in the universe and thus may be integrated into a basic unified force.*

Weinberg became involved with issues related to cosmology, the origin of the universe, and the big bang. Weinberg, his colleague Abdus Salam, and other scientists continue to search for "superstrings" that may link these four basic forces. Their superstring theory states that all the known small particles of matter are not really the basic fundamental particles. Rather, an extremely small (not yet detected) vibrating string is the basic particle or energy unit, possibly only 10^{-35} cm, which is smaller than anything yet to be conceived. Instead of three or four dimensions, the "strings" supposedly may have six dimensions, each of which is curled up into each string. The advantage of the string theory is its ability to explain the unification of all four of the natural forces, the big bang theory, and black holes. Weinberg currently believes we are on the verge of uncovering the final theory, which Albert Einstein referred to as the unified field theory. It has also been referred to as the grand unification theory (GUT), the theory of everything (TOE), and the "answer."

See also Einstein; Glashow; Hawking; Salam; Witten

WEISMANN'S GERM PLASM THEORY: Biology: *Friedrich Leopold August Weismann* (1834–1914), Germany.

> *Germ plasm (today known as genetic resources or DNA) that is found in the ovum and sperm, which, in turn, are part of the chromosomes of living cells of organisms, are responsible for the continuity of characteristics from parent to offspring.*

Weismann stated that there were two types of cells in multicellular organisms: germ cells and somatic cells. The distinction that Weismann made between the two types of cells was that the "germ plasm" or protoplasm found in germ cells is passed unchanged from one generation to the next. In other words, germ plasm (not to be confused with "plasma") is responsible for inheritance of characteristics from one generation to the next. He considered somatic cells merely as a vehicle (means) to transport the germ plasm that is supposedly "immortal" because it passes inherited characteristics from generation to generation of a species. He was one of the first to propose that the germ plasm in the germ cells is protected from any type of modification by environmental (external) effects on the cells. This is now called the "Weismann barrier" that became a strong point in Darwin's theory that acquired characteristics cannot be inherited. The Weismann barrier led to a renewed interest in Gregor Mendel's work with inheritance that had been more or less ignored by scientists for many years. It also disproved Lamarckian theory of inheritance, which incorrectly stated that acquired characteristics can be passed on through germ plasm and thus inherited (as an example, Lamarck believed that if a woman dyed her hair red before conception, the resulting child would have red hair). The Soviet biologist Trofim Denisovich Lysenko, who was the minister of agriculture under Stalin, attempted to implement some of Lamarck's ideas of how to use environmental factors to improve genetics of the seeds of agriculture crops with catastrophic results. These measures resulted in the repeated failure of several generations of food crops and starvation in Russia. Weismann conducted an experiment designed to disprove Lamarckism by cutting off the tails of twenty-one generations of mice. He found that the offspring of the twenty-second generation still had tails, thus proving that injury (an acquired characteristic) is not heritable.

Although Weismann did not completely understand genetics, he did make some contributions to evolutionary biology. For example, he discovered what became known as "crossing over during meiotic division of gametes," and he understood the process of genetic variability as the basis of natural selection. He was the first to suggest that sexual reproduction was a means of providing new variations required for natural selection to work. More recently it has been found that the organism may be affected by some modification of germ plasm, such as changes in the immune system. Even so, the Weismann barrier is fundamental to Darwin's theory. Weismann wrote several important books in his lifetime. *Studies in the Theory of Descent* in 1882 contained a preface by Charles Darwin. In 1886 he wrote *The Germ Plasm:A Theory of Heredity*.

See also Darwin; Lamarck; Mendel

WEIZSÄCKER'S THEORIES OF STAR AND PLANET FORMATION: Physics: *Baron Carl Friedrich von Weizsäcker* (1912–2007), Germany.

Weizsäcker's theory of star formation: *A nuclear chain reaction involving a ''carbon-cycle'' occurs inside a condensed mass of gas, resulting in the formation of a star that produces heat and light.*

In 1929 George Gamow was the first to propose that the source of a star's "core" energy is a nuclear reactor where hydrogen nuclei are converted into helium nuclei by the process of nuclear fusion, resulting in the release of vast amounts of energy. Several years later, when more was known about nuclear reactions, Hans Bethe provided the details of how hydrogen fusion could occur in the sun's core without exploding the star. Baron Carl Weizsäcker advanced a similar theory with the addition of what is known as the "carbon cycle" or the "carbon-nitrogen cycle" (not to be confused with the biosphere carbon cycle). Weizsäcker believed that in massive stars, a carbon molecule attracts four protons (hydrogen nuclei), and through a series of theoretical nuclear reactions, it produces one carbon nucleus and one helium nucleus while emitting two positrons and tremendous heat and light energy ($C + 4\ {}^{+}H \rightarrow C + {}^{++}He + 2\ {}^{+}p$). Because stars are composed mainly of hydrogen, this process, which takes place at their centers, can continue until all the hydrogen is converted to helium. However, a time span of billions of years must pass before "death" occurs for most stars. In addition to great amounts of heat and light produced by stars, the triple-alpha process, a nuclear reaction in stars, fuses three helium atoms to form carbon, which makes carbon-based life on Earth possible.

Weizsäcker's nebula/planetary hypothesis: *As a nebula of swirling gases and small particles condenses, turbulence is created that will form the planets in their orbits.*

There is a long history of ideas, concepts, hypotheses, and theories to explain the origin of the solar system and its planets. One of the more popular ideas was the "passing star" theory, which explained how matter was pulled off two stars as they passed close to each other to form planets orbiting around one or both stars. In 1944 Weizsäcker applied mathematics related to the science of **magnetohydrodynamic**s to explain how a mass of thin gas moving in a giant magnetic field in space could, through angular momentum, "push" the energy of the moving gas outward, thus providing angular momentum for the planets to remain in their orbits. One problem was that planets exhibit more angular momentum than Weizsäcker predicted, and angular momentum is always conserved; it cannot be created or destroyed, just transferred. Weizsäcker's nebula theory, with modifications that use the sun's magnetic field to increase the angular momentum of the planets (provided by Fred Hoyle), is currently the best explanation for the formation of our solar system.

See also Bethe; Gamow; Hoyle; Laplace

WERNER'S COORDINATION THEORY OF CHEMISTRY: Chemistry: *Alfred Werner* (1866–1919), Switzerland. Alfred Werner was awarded the Nobel Prize in Chemistry in 1913.

> *Metals have a primary and secondary valence—the primary valence involves the binding of ions (charged atoms), while the secondary valences involve atoms and molecules to form "coordinated compounds" of metals.*

Alfred Werner received his PhD in chemistry from the University of Zurich in 1890. Several years later in 1895 he returned to the university as professor of chemistry where his work revolutionized inorganic chemistry by distinguishing between a primary and secondary valence for metal atoms. He showed that the primary valence of a metal (mostly a transition metal) was involved with the binding of ions (atoms with a charge), whereas the secondary valence of a metal was applied to both the atoms and molecules. This characteristic made it possible for some metals, by the use of secondary valences, to join with themselves to form what Werner called "coordination compounds." A coordination compound is a metal surrounded by molecules or ions that are called "ligands" or complex agents. When a metal ion has an empty valence orbit, it can form an acid. Werner's theory of the number of atoms or groups of atoms, involved with a central metal atom led to the concept of a "coordination number" of 4 or 6 up to maximum number of 8, which then led to Abegg's rule known as the "rule of eight." The Werner coordination theory for transition metals was the beginning of modern inorganic chemistry in the early twentieth century.

See also Abegg

WERNER'S NEPTUNIAN THEORY (NEPTUNISM): Geology: *Abraham Gottlob Werner* (1750–1817), Germany.

> *As the great flood that covered the ancient Earth subsided, the dissolved minerals were chemically precipitated out to form the different types of rocks, minerals, and surface features including the mountains.*

Although a discredited scientific theory, Werner named his concept for the formation of rocks after the ancient Roman name (Neptunus) for the Greek god of the sea, Poseidon. The theory was also based on biblical scriptures and Werner's observations of the indigenous minerals and ores of the mining regions of his birth. As a young boy he became an assistant to his father who was a supervisor of an ironworks operation in northern Germany. Abraham entered the Freiberg Mining Academy in 1769 and later transferred to the University of Leipzig from which he graduated in 1775. He retuned to teach at the mining academy where he developed his theory. Neptunian theory explained how an Earth-covering sea receded in several steps by varying rates of chemical precipitation, thus forming different types of crystalline rocks. The first layer of the crust consists of very old igneous rocks such as granite, gneiss, and slates that contain no fossils. The precipitates from the oceans formed these old rocks before dry land appeared. Next was the transitional strata consisting of shale that contained fossils of fish. This layer was followed by the secondary strata of various types of limestone and sandstones that made up the secondary rocks. The alluvial or tertiary strata was next and consisted of gravels, sand, and clays that were formed as the oceans receded from the continents. Finally, once the water subsided, the exposed dry land contained lava produced by volcanoes, as well as other deposits. For a time, Werner's theory was accepted and even displaced other older theories for the formation of rocks such as the Plutonist's theory proposed by the Scottish geologist James Hutton (1726–1797) who suggested that igneous rocks were formed by molten matter. Werner was also a mineralogist who published the first textbook on minerals based on his classification of minerals. Although he eventually realized such a classification should be based on chemical characteristics, his book emphasized the need for correct classification based on the external characteristics and physical properties of minerals. All three factors (chemical, external characteristics, and physical factors) should be considered for any accurate classification. Also, he did not recognize the importance of the various types of crystallization in rocks as a means of identifying different types of minerals and ores. His theory for the origin of mineral and ore deposits followed his general theory of geology. He stated that precipitates filled the fissures that developed on the worldwide oceans' seafloors forming veins of minerals. This idea was opposite of the Plutonists who claimed that molten matter from the center of Earth filled these cracks with vapors to form deposits of minerals. Werner, who suffered from poor health his entire life, retired in Dresden, never married, and died in 1817.

WHEELER'S "GEON" THEORY: Physics: *John Archibald Wheeler* (1911–2008), United States.

> *Geometrodynamics (geon) is an electromagnetic field maintained by its own gravitational attraction.*

John Wheeler searched for a theory to unify two seemingly unrelated fields: gravity and electromagnetism. This involved a method to demonstrate the concept of "action at a distance." Since the days of Aristotle, it was believed that something had to push or pull an object continually to make it move or cease moving. Neither did the ancients believe an object could be moved by a force not in direct contact with it. This was implicit in Newton's third law of motion (for every action, there is an equal and opposite reaction). Wheeler and his colleague, Richard Feynman, offered a solution that proposed a retarded effect on an object rather than an instantaneous effect. Their solution, somewhat like one of Einstein's "thought experiments," does not require any laboratory or equipment. Wheeler and Feynman suggested that two objects (1 and 2) be set up exactly one light-minute apart (1/525,600 of a light-year). Then any light (or any electromagnetic wave) sent from object 1 will take exactly 1 light-minute to reach object 2. Thus, it could be said that there was a delay from the signal to the reception of 1 light-minute, or because the action was received after it was sent, it was "retarded." In addition, there was no direct or instantaneous contact between the forces exerted by object 1 with the retarded action by object 2. Gravity and electromagnetism exhibit some properties of "action at a distance," which is one reason Wheeler attempted to unify them into a single theory. However, one problem was Newton's third law (if there is a "forward" effect from object 1 to object 2, there should also be an effect acting "backward" from object 2 to object 1). This problem could be eliminated only if "retarded" effects were considered. Geon unification theory has never been proved. Wheeler made contributions to the area of nuclear fission and from 1940–1950 worked at the Los Alamos Laboratory exploring the possibility of using heavy hydrogen to make a hydrogen (fusion) bomb.

See also Feynman

WHIPPLE'S "DIRTY SNOWBALL" THEORY OF COMETS: Astronomy: *Fred Lawrence Whipple* (1906–2004), United States.

> *Comets are composed of ice, dust, gravel, some gases, and possibly a small rocky core. They are similar to a dirty snowball.*

In 1949, astronomer Fred Whipple based his comet theory on the spectroanalysis of their light and their evolution as they made return trips on elliptical paths through the solar system. He theorized that comets are basically formed of ice and contain a mixture of sand-like dust, gravel, and possibly some gases, such as carbon dioxide, methane, and ammonia. Some comets may have a rocky core. Whipple explained that when a comet approached the sun, even millions of miles distant, the comet's ice vaporized, expelling the dust and gas to form a hazy tail, which always pointed away from the sun as it continues on its orbit. This is a major feature of Whipple's theory. Comets have three basic parts: the head, which is the brightest, varies in size from 0.5 to about 5 or

7 miles wide; a halo, which may be 50,000 to 75,000 miles wide, that glows around the head; and the tail, which is a much fainter glow and may extend 50 to 75 million miles in front of the head. Sunlight and solar wind create radiation pressure on the comet, which forces the gaseous ice/dust of a comet's tail always to point away from the sun. Thus, the "tail" of the comet always precedes the head of the comet because of the solar pressure on the comet's tail, which is less dense than the comet's head. In 1986 a U.S. spacecraft investigating and gathering data on Halley's comet confirmed Whipple's theory of a comet's structure, with one exception: rather than being a "dirty snowball" of dust, it is now believed to be more like an "icy dust-ball" because the ice is condensed on the outside of the dust particles, and after each pass around the sun, more and more of the ice is lost, meaning that the comet becomes less and less brilliant as it ages.

See also Halley; Oort

WHITEHEAD'S "ACTION-AT-A-DISTANCE" THEORY OF RELATIVITY: Mathematics and Physics: *Alfred North Whitehead* (1861–1947), England and United States.

> *Action-at-a-distance is the interaction of two objects in space that are separated from each other but still interact with no mediator or connection.*

The ancients, including Aristotle, believed that for an object to move either on Earth or in the heavens, something had to either push or pull it; or if the push or pull was removed, the object ceased moving and no interaction was present. When more was learned about gravity and electromagnetism, these theories were used to partly explain this phenomenon. Einstein referred to this as "spooky action at a distance" and claimed it was evidence of quantum theory, general relativity, and gravity. Whitehead disagreed with Einstein's theory of relativity and developed his own "action-at-a-distance" theory that was based on philosophical principles. It was and never has been well accepted because it lacked any evidence.

Alfred North Whitehead was one of the most famous and last of the nineteenth century's philosopher/scientists who approached science more by using philosophical reasoning than by gaining evidence through research. He adopted a belief in "atomic occasions," which were different and succeeded one to another endlessly as a way to explain time and nature as well as his belief in a supreme being. He related the ultimate uniformity as in the nature of God. His father, also named Alfred Whitehead, was an Anglican preacher who home-schooled his son until the age of fourteen. The younger Whitehead was considered "sickly" by his parents, but after he entered public school, he excelled in sports and seemed to be a healthy child. In 1884 he graduated with a PhD from Cambridge University in England where he later became a teacher. One of his students, Bertrand Russell (1872–1970), became a fellow philosopher of science and a mathematician who objected to the materialistic and deterministic direction of nineteenth-century science that developed scientific theories where patterns were derived from the perceptions and measurements of the world rather than the basic properties of reality. This philosophical viewpoint was expressed in Whitehead's first book *Treatise on Universal Algebra* published in 1898. In 1910 he published his most important book, *Principia Mathematica* coauthored with Bertrand Russell. Whitehead did not contribute to the second edition of this book published by Russell in 1925. The original volume is considered one of the most influential works in the field of logic, on a par with Aristotle's *Organon*.

WIEN'S DISPLACEMENT LAW: Physics: *Wilhelm Carl Werner Otto Fritz Franz Wien* (1864–1928), Germany. Wilhelm Wien received the 1911 Nobel Prize in Physics.

> *As the temperature rises for electromagnetic radiation, the total amount of radiation increases, while the wavelength of the radiation decreases.*

Wilhelm Wien knew that the amount of electromagnetic radiation increases as temperatures rise (a glowing red-hot stovetop element feels hotter than one that is not glowing and appears black). He also knew that very long and very short wavelengths are less abundant in nature than those near the center of the electromagnetic scale. After measuring various wavelengths, he determined these central "peak" wavelengths vary inversely with the **absolute temperature.** This is known as *Wien's displacement law*: the temperature of the radiation determines wavelength and amount of thermal radiation. Heating a hollow metal ball with a hole in it, called a "blackbody," and then measuring the wavelength and amount of radiation emitted demonstrates this law. As the temperature of the blackbody increases to the red-hot stage, longer wavelength radiation is emitted. When the temperature becomes even greater, white-hot shorter wavelength radiation is detected. The "amount" of radiation peaks at about the same wavelength range as that of visible light on the electromagnetic radiation scale. The law can be expressed as: λ T = constant, where λ is the wavelength, T is the temperature, and the constant is equal to 0.29 cm k. Wien used this law to indicate the distribution of energy in the spectrum as being a function of temperature. The law is applicable for shorter wavelengths but breaks down for longer wavelengths. The blackbody radiation distribution law (the beginning of quantum theory), developed by Max Planck, is equivalent to Wien's displacement law when the frequency is very large. Planck's law is correct at any frequency, whereas Wien's is correct only for high frequencies.

See also Bohr; Boltzmann; Einstein; Helmholtz; Planck; Schrödinger

WIGNER'S CONCEPT OF PARITY/SYMMETRY IN NUCLEAR REACTIONS: Physics: *Eugene Paul Wigner* (1902–1995), United States. Eugene Wigner shared the 1963 Nobel Prize for Physics with Maria Goeppert-Mayer and J. Hans Jensen.

> *Parity is conserved in nuclear reactions because nature cannot differentiate between left and right orientations or between time periods.*

Eugene Wigner, a theoretical physicist, contributed to the understanding of nuclear physics by applying quantum theory to fundamental symmetry principles. He stated that parity is conserved in nuclear reactions. (Any two integers have parity if they are both even or both odd, and fundamental physical interactions do not distinguish between right or left or clockwise or counterclockwise, thus ensuring symmetry, which is a major physical concept.) Wigner's theory stated that for all matter, energy, and time in the universe, nature makes no distinction between the physical orientation in space of particles, or of more or less time. This relates to nuclei and subnuclear particles' having mirror images, as they are involved in all types of chemical and nuclear reactions. In other words, it does not matter if the molecules or nuclei of matter are oriented as mirror images of each other. The results will be identical in the same time period. Or if a particle is ejected from a nucleus, no distinction is made as to whether it leaves from the right or left. This theory was accepted until 1958, when weak nuclear reactions were discovered. An example of a weak nuclear interaction is the decay of a neutron into a proton plus a beta particle (electron) and a neutrino; parity is not conserved. Even so, this exception does not eliminate the concepts of a parity or symmetry. Wigner's concepts of parity and symmetry are related to the premise that the greater the "cross section" of a nucleus, the more likely it is that the nucleus can absorb a neutron. This idea contributed to the successful production of a sustained chain reaction in the first nuclear pile located under Alonzo Stagg field stadium at the University of Chicago in 1942.

See also Boltzmann; Fermi; Schrödinger; Weinberg; Wu; Yang

WILKINSON'S CONCEPT OF "SANDWICH COMPOUNDS": Chemistry: *Sir Geoffrey Wilkinson* (1921–1996), England. Geoffrey Wilkinson shared the 1973 Nobel Prize in Chemistry with Ernst Fischer.

> *Homogeneous catalysts can be formed by adding hydrogen to the double bonds of alkenes.*

Geoffrey Wilkinson, primarily an inorganic chemist, explored the attachment of hydrogen to metals to form complex compounds (hydrides) composed of molecules sandwiched together with hydrogen bonds that could be used as catalysts, later known as *Wilkinson's catalysts*. Using these catalysts, he developed systems that could alter the nature of organic compounds by adding hydrogen to the double bonds of some hydrocarbon type molecules. By bonding hydrogen to compounds known as *alkenes*, which have unsaturated molecules, he converted them into branched-chained hydrogen-saturated, paraffin-type compounds. Known as *addition hydrogenation*, this process converts unsaturated vegetable liquid oils (e.g., corn oil) to solid fats (e.g., margarine) by adding hydrogen to the double bonds of the oil molecules. This hydrogenization process may also rupture these organic bonds, resulting in hydrocracking, hydroforming, or catforming, which splits off sections of hydrocarbon molecules by using low heat and a platinum catalyst. This process converts crude petroleum into more useable branched-chained fractions (e.g., gasoline, ethane, propene). It is also known by a more generic name, *hydrogenolysis*, which converts bituminous coal into a variety of useful hydrocarbon products, including coal tar dyes, medicines, cosmetics, lubricants, and other petroleum-like products (e.g., "coal-oil" or kerosene).

WILLIAMSON'S THEORY OF REVERSIBLE CHEMICAL REACTIONS: Chemistry: *Alexander William Williamson* (1824–1904), England.

> *A chemical reaction will reach dynamic equilibrium when, under correct conditions of concentration, temperature, and pressure, it becomes reversible.*

Alexander Williamson demonstrated that it was possible to produce a number of different organic compounds by replacing one or more hydrogen atoms in organic compounds, thus forming organic radicals. He based his idea on the work of the French chemists Charles Gerhardt (1816–1856) and Auguste Laurent by replacing one or more hydrogen atoms in inorganic compounds that form typical radicals. From this, he developed chemical formulas for a number of compounds, such as alcohols and ether. While experimenting with these new substances, he discovered that some chemical reactions are reversible. A mixture of two compounds will react to form two very different compounds. However, using the correct amounts of the initial substances along with the correct temperature, concentration, and pressure, the reaction will reverse itself, and the new compounds will revert to the original substances. In other words, once the first two compounds form the second two, the second ones will revert to the original two compounds ($A + B \leftrightarrow C + D$). Under these conditions the entire system is considered to be in dynamic equilibrium. This process is known as *Willliamson's synthesis* and is used in the making of ethers. This concept is vital to the chemical industry concerned with the conditions necessary to ensure a chemical reaction is not in equilibrium so that it will proceed in the desired direction, resulting in the preferred product.

See also Laurent

WILSON'S HYPOTHESIS OF CLOUD CONDENSATION: Physics: *Charles Thomson Rees Wilson* (1869–1959), England. Charles Wilson received the 1927 Nobel Prize in Physics.

> *If dust-free, supersaturated moist air is rapidly expanded, the moisture condenses on both fine nuclei and ions (particles).*

While experimenting with supersaturated water vapor in a laboratory vessel, Charles Wilson rapidly expanded the volume of this moist air, which formed a cloudlike formation in the chamber. Because the air was dust free, he assumed some type of "nuclei" were present, which provided a base for the moisture to condense into water droplets. He theorized that the recently discovered radiation called X-rays might also cause condensation tracks to form in the moist air in his chamber. Subsequently, he discovered that supersaturated air became conductive when X-rays passed through this moist air, and much more condensation was produced than could be caused by just expanding the air's volume. Wilson then developed his famous *Wilson cloud chamber*, based on the work of J.J. Thomson and Ernest Rutherford, which detects radioactive radiation of all kinds as well as very small, almost weightless subatomic particles as they form ionized curved paths through supersaturated air in the chamber. In the early part of the twentieth century the Wilson cloud chamber became a valuable research tool for the study of subatomic particles. These ionized paths in the chamber made by radiation form water droplets and can be photographed and studied to determine the characteristics of the radiation or nature of the subatomic particle.

See also Compton; Millikan; Rutherford; Thomson

WILSON'S "OUT-OF-AFRICA" THEORY: Biology: *Allan Charles Wilson* (1934–1991), New Zealand.

The ratio of mitochondrial DNA differences between humans and great apes indicates a divergence of lineages five million years ago, which achieved a complete separation between species two hundred thousand years ago.

Allan Wilson studied the DNA found in the mitochondria of cells that, unlike regular DNA, is found outside the cell nucleus. Mitochondria exist in the **organelles**, which are structures located in the cytoplasm that produce the energy required for cell growth and life. This extranuclear DNA, referred to as $_{mt}$DNA, is carried only in the mother's cells. It is also believed that genetic variations arise from mutation of the $_{mt}$DNA and accumulate through the maternal side at a rather steady rate, which provides a means to calculate statistically, through maternal $_{mt}$DNA, the age of ancestors. In other words, $_{mt}$DNA becomes a *molecular clock*. Wilson therefore theorized that all human mitochondrial $_{mt}$DNA must have originated with a very old, common, female ancestor. He collected a sample of mitochondria cells from individuals of all races from all parts of the world and discovered there are just two basic genetic branches, both of which originated in Africa. His theory that the maternal ancestor for all humans lived on the African continent became known as the "out-of-Africa" theory and was later dubbed the "Eve hypothesis" by journalists.

Wilson's next research dealt with the age of this "common" female ancestor. He found the ratio of $_{mt}$DNA between chimpanzees and humans was 1:25. Also, because the beginning of the separation of the *Homo* species from the great apes was about five million years, he calculated that 1/25 of this five million years was equal to two hundred thousand years. (More recently it has been established that chimpanzees and humans share over 98% of the same DNA.) He theorized this was the time a complete separation from our nonhuman ancestors resulted in a human species. Some scientists claim humans diverged from apes and became a separate species in more than one geographical region. Some paleontologists claimed that the divergence of humans from apes occurred over five million years ago; other scientists claim this divergence occurred no more than one million years ago. In 1980 Wilson wrote that the years of divergence was more than two hundred thousand years ago, whereas others believe it occurred fewer than two hundred thousand years ago. A competing theory, called "multiregionalism," proposes that ancient humans originated in several different regions of the world and over time migrated, interbred, and produced hybrids that became some of the now-extinct species of the *Homo* group (e.g., Neanderthal man). Most scientists now accept that the extinct species of *Homo* who walked erect on two legs developed about 100,000 to 200,000 years ago in Africa, 60,000 years ago in Australia, 40,000 years ago in Europe, and 35,000 years ago in Northeast Asia and appeared in the northwestern part of the North American continent about 15,000 to 30,000 years ago. The more recent species of man, *Homo sapiens-sapiens* (intelligent man), appeared in Europe or Eurasia about ten thousand to fifteen thousand years ago. More fossil evidence will need to be found and analyzed before the argument concerning the origin of humans as a separate species can be settled.

WILSON'S THEORY OF DYNAMIC EQUILIBRIUM OF ISLAND POPULATIONS: Biology: *Edward Osborne Wilson* (1929–), United States.

Geographically isolated species will establish a dynamic equilibrium of their populations.

E. O. Wilson is an entomologist and sociobiologist who studied ants and other social insects. Wilson and his colleague, the ecologist Robert MacArthur (1930–1972), theorized that, in time, related species would develop distinct differences to resist interbreeding, and a "dynamic equilibrium" of their populations would naturally be established. They based their concept on what they called "character displacement," which takes place when isolated species are once again brought back into close geographic proximity to each other. To prove their theory, they eliminated all insects on a small island off the south Florida coast and waited to see how it would be repopulated as compared to the original number of species. After several months, they returned to find that the same number of species in the same ratios had repopulated the island, as before, thus proving their theory that for isolated geographic areas, a dynamic equilibrium among species populations will develop (they assumed the insects' eggs were not completely destroyed or adults arrived from other nearby land areas). Wilson also contends that individual animals and groups (insects and humans) use their genetically driven cultural attributes, which are the result of natural selection, to control their population and make sacrifices for the group.

See also Darwin; Wallace

WITTEN'S SUPERSTRING THEORY: Physics: *Edward Witten* (1951–), United States.

Events at the nuclear level unify general relativity by combining gravity, quantum mechanics, and space in ten dimensions.

There are two major theories of physics: 1) the very small (quantum theory and the uncertainty principle as related to atoms, molecules, subatomic particles, and radiation) and 2) the very large (Einstein's theory of general relativity, gravity, the cosmos, black holes, etc.). Both are related to the Standard Model of quantum mechanics (*see* Schrödinger). Edward Witten was convinced that the string theory could resolve the problems encountered when combining these two great theories that deal with the small and large. Usually a minute elementary particle is defined as a "point." Witten redefined fundamental particles as a vibrating string or looped string that has different states of oscillation with harmonics similar to a vibrating violin string, making them somewhat "fuzzy" point sources. Therefore, a single string can have several harmonics and can consist of a large grouping of different types of elementary particles. This results in a spectrum of particles that then can be "quantized" and related to the "graviton," referred to as the *quantization of gravitational waves*, which in itself makes gravity a priori of the string theory. All types of minute particles and subatomic particles (e.g., electrons, protons, muons, neutrinos, and quarks) fit into the string theory. Thus, Witten claims to have combined the quantum mechanics aspect of the electromagnetic/small with the quantum of relativity/gravity of the large. Based on pure mathematics, Witten proposed how a space consisting of two, four, six, or ten dimensions can explain superstrings and how particles can interact within such a geometric formation, and that six of these dimensions are "folded" into the four known dimensions (height, width, depth, and time). The original string theory was based on the notion that just after the big bang, as the universe cooled, cracks and fissures formed in space that contained great masses, energy sources, and gravitational fields. Recently, Steven

Hawking claimed that no evidence exists to support the existence of strings; thus the great unification of Einstein's general relativity and gravity with electromagnetism remains elusive. However, string theory remains a somewhat contentious subject in the science community. There are hundreds of young theoretical physicists who continue to work on the string theory because they believe it will lead to a grand unification theory or a theory of everything, while there are a few others who claim that there is no physical observable evidence to justify the acceptance of a theory based on tiny strings and multiple dimensional universes.

See also Einstein; Hawking; Schrödinger; Weinberg

WOHLER'S THEORY FOR NONLIVING SUBSTANCES TRANSFORMING INTO LIVING SUBSTANCES: Chemistry: *Friedrich Wohler* (1800–1882), Germany.

> *By applying heat, it is possible to convert nonliving (inorganic) molecules to living (organic) molecules.*

Friedrich Wohler's experiments challenged "vitalism," the prevailing theory dealing with organic chemistry of the 1800s that stated it was not necessary to explain the compounds that make up living organisms because there was a "spirit" connected to life. This spirit was the God-given "vital essence" in all living things, including organic molecular compounds. Vitalism was accepted as the reason humans cannot and should not transform nonliving chemicals into living substances. Wohler proved otherwise, which not only resulted in the beginning of the end of vitalism, but provided understanding of new concepts for inorganic and organic chemistry. In 1928 he used heat to decompose ammonium isocyanate, an inorganic chemical, into urea, an organic chemical found in urine (NH_4NCO + heat $\rightarrow$ NH_2CONH_2) (these are two very different compounds but with the same molecular formula, thus they are isomers). Vitalism is a persistent theory and still has adherents. In the field of chemistry, Wohler's work pioneered modern organic chemistry (carbon chemistry), particularly as related to human physiology of respiration, digestion, and metabolism.

WOLFRAM'S THEORY OF COMPLEX SYSTEMS: Physics: *Stephen Wolfram* (1959–), England.

> *Complex systems are driven by one-dimensional cellular automata that follow specific rules.*

Stephen Wolfram was interested in a theoretical model for parallel computing that would increase computational power. This idea is based on the ability to understand entities consisting of a group of "cells" (not to be confused with living cells) that are controlled by a series of rules leading to complexity and chaos. Complex systems are based on the concept of *cell automata* first proposed by John von Neumann. There are several rules for one-dimensional automata cells:

- All cells in a "set" may or may not be filled in.
- Patterns may alternate from "filled in" to "not filled in" and continue to change, but each set must be one way or the other.

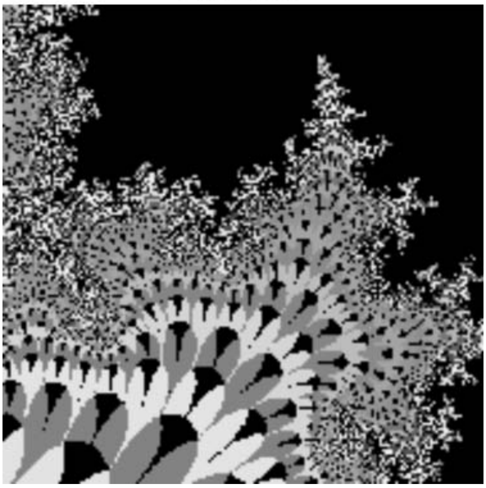

Figure W1. Fractals are ''self-similarities'' or ''self-replacing'' patterns that become increasingly complex and chaotic as they progress. They are similar to Penrose tiles connected in repeated diminishing patterns of geometric shapes as related to chaotic behavior.

- These patterns may "grow" and continue to form the same patterns in ever increasing complexity, as in self-replicating fractal patterns.
- These patterns will continue to become increasingly complex and chaotic.

This theory of complexity and self-organization explains many natural systems, including how simple organic molecules combined to form increasingly complex patterns until they could become self-replicating and thus living. The theory also describes formal language theory related to the evolution of grammar and original languages into the modern languages of the world.

See also Penrose; von Neumann

WOLF'S THEORY OF THE DARK REGIONS OF THE MILKY WAY: Astronomy: *Maximilian Franz Joseph Cornelius Wolf* (1863–1932), Germany.

> *The dark areas of the Milky Way galaxy are regions where dense ''clouds'' obscure some of the stars.*

Maximilian Wolf designed the *Wolf diagram* used to measure not only the absorption of light but also the distance from Earth to what was called "dark nebula." He attached a camera to the eyepiece of a telescope, enabling him to expose photographic plates and thus record observations over long periods of time. By using time exposure, more light from distant and dim objects was gathered, allowing him to view images on the photographic plates that could not be seen otherwise. Using these methods, Wolf theorized that the dark areas in the Milky Way are gas clouds. More recently it was proposed that over 90% of all matter in the universe is composed of **dark matter**, gas, or even **neutrinos**, none of which can be seen by visible light and which outweighs all the trillions of stars.

WOODWARD'S THEORY OF ORGANIC MOLECULAR SYNTHESIS: Chemistry: *Robert Burns Woodward* (1917–1979), United States. Robert Woodward received the 1965 Nobel Prize in Chemistry.

> *Molecules of organic substances maintain an orbital symmetry enabling them, by geometric orientation, to rotate 180° degrees on their axes and thus become a ''negative'' mirror image of the organic molecules.*

Robert Woodward used the principle of symmetry related to molecular orbits to develop his theory of how some molecules, through a series of addition-reactions, can be synthesized into many useful chemical products. He expanded organic synthesization to the formation of complicated molecules, some involving as many as fifty sequences or series of chemical reactions. Some examples of the products resulting from his addition-reactions are quinine, cholesterol, cortisone, lysergic acid (LSD), reserpine, strychnine, chlorophyll, and vitamin B_{12}.

See also Couper; Kekule

WRIGHT'S THEORY OF GENETIC DRIFT (SEWALL WRIGHT EFFECT): Biology: *Sewall Green Wright* (1889–1988), United States.

> *In a small isolated population certain forms of genes may be randomly lost because they are not passed along to the next generation.*

The "Sewall Wright effect," also known as "the genetic sampling error," explores the changes in the gene pool of a small isolated and restricted population where there is a loss of particular genes and their characteristics that may lead to the emergence of new species. Within this small community natural selection does not usually take place due to inbreeding. He used statistics to determine the inbreeding coefficient as a way to compute the pedigrees within the local population. Sewall Wright and Sir Ronald A. Fisher (1890–1962), the British evolutionary biologist, computed the amount of inbreeding among members of populations as a result of random **genetic drift**. Together they developed the methods for computing the interactions of natural selection, mutation, migration, and genetic drift.

Sewall Wright's family lived in Melrose, Massachusetts, where as a young boy he deliberately dropped his middle name (Green). In 1892 his family moved to Galesburg, Illinois, where he attended high school and Lombard College. He then moved onto the University of Illinois where he received his PhD in biology in 1915. He spent the remainder of his career in research and teaching at other universities including the University of Chicago, University of California at Berkeley, and as a Fulbright Professor at the University of Edinburgh in Scotland (1949–1950), and finally at the University of Wisconsin–Madison.

WRINCH'S CYCLOL THEORY OF PROTEIN STRUCTURE: Biochemistry: *Dorothy Maud Wrinch* (1894–1976), England and United States.

> *Chromosomes composed of sequences of amino acids are the only molecules with sufficient variety to permit the construction of complex molecules.*

Dorothy Wrinch had an eclectic academic career that included contributions in the areas of mathematics, biochemistry, philosophy, physics, as well as in sociology. She was born in Argentina in 1894 to a British couple who soon after her birth moved back to England. After graduation from high school, she received a scholarship to attend Girton College in Cambridge where she was influenced by Bertrand Russell to study philosophy and mathematics. She graduated with a first-class degree in mathematics in 1916, followed with a MSc and a DSc in mathematics from University College in London. After marrying John William Nicholson, who was the director of mathematics and physics at Balliol College at Oxford, she moved with him to Oxford where she taught mathematics at several women's colleges. During this time she earned her second master's degree in 1924 and her second doctorate degree in 1929. This was the first doctorate degree awarded to a woman by Oxford University. She published papers in the areas of applied mathematics and the philosophy of science. In the early 1930s Wrinch separated from her husband who by this time had become an alcoholic (they divorced in 1938). All the while she continued to receive fellowships in the new field of mathematics related to physics, chemistry, and biology.

She spent time at several European universities and in the mid 1930s she wrote five papers on the application of mathematics to chromosomes. This earned her a Rockefeller Foundation fellowship to study the application of mathematics to biological molecular structures. She traveled to several universities in the United States where she explained her theory of cyclol protein structure, which was based on concepts of mathematical symmetry.

Other scientists had suggested a hypothesis for the structure of fibrous protein by hydrogen bonding. Wrinch developed this suggested hypothesis in a viable model of protein structure. In 1936 her first cyclol model was presented in a paper that noted the possibility that polypeptides could cyclize and form closed rings that could form internal cross-links through what is known as cyclol reactions and thus could form stable peptide bonds. She figured out that such cyclol molecules would have a six-sided symmetry if the bonds were similar. This means that such rings can extend indefinitely to form what is known as "cyclol fabrics" that are proteins with no side chains. She presented this structure as a working hypothesis. After more research over the next few years, it was found that her cyclol hypothesis model was not accurate for globular proteins.

Although her theory was not entirely correct, it was useful when applied to chemical bonding and the study of organic compounds. During the early years of World War II in Europe she moved to the United States as a visiting lecturer in chemistry at Johns Hopkins University in Maryland. Dorothy became a visiting professor at Amherst and Smith Colleges and met Otto Charles Glaser who was a vice president at Amherst. They married in 1941. In 1943 she became a research professor of physics at Smith College in Massachusetts where she received a long-term fellowship in 1965. She retired from Smith in 1971 and moved to Woods Hole in Massachusetts. Her book on mathematical principles for the explanation of X-ray crystallography of complex crystal structures was published in 1946. It is titled *Fourier Transforms and Structure Factors*. Her theory of protein structure encompassed chemistry, physics, mathematics, as well as philosophy and contributed to molecular biology as a multidisciplinary study of life. Although her cyclol model for globular proteins was not completely accurate, it was a precursor for scientists to research the protein structure and develop a hypothesis for the DNA double-helix structure.

See also Crick–Watson

WU'S THEORY OF BETA DECAY: Physics: *Chien-shiung Wu* (1912–1997), United States.

> *The direction of the emitted beta particle is related to the direction of spin of the nucleus from which it originates.*

In 1934 Enrico Fermi verified Wolfgang Pauli's concept of beta decay, where a neutron disintegrates into an electron and neutrino, leaving behind a proton: neutron →

electron (β) + neutrino + proton (*see* Figure F2 under Fermi). This process is also known as the *nuclear weak force*, which is stronger than gravity but much weaker than the *strong nuclear force* that holds nuclei together. But there were problems with the Pauli/Fermi theory. In 1957, Chien-shiung Wu theorized that the problem was the direction of the beta decay. She demonstrated that the direction of emission of the beta particle was related to the spin orientation of the nucleus that was decaying. Thus, the emission process of the system is not identical to the mirror image of the system, and therefore parity (right–left symmetry) is not conserved during beta emission. Parity means that two systems that are mirror images of each other are the same in all respects except for this left–right or mirror image phenomenon and therefore should retain identical symmetry just as humans have a left-and-right side (mirror image) but also have bilateral symmetry.

See also Fermi; Feynman; Pauli; Wigner; Yang

WURTZ'S THEORY FOR SYNTHESIZING HYDROCARBONS: Chemistry: *Charles Adolphe Wurtz* (1817–1884), France.

> *Hydrocarbons, including aromatic hydrocarbons, can be synthesized by reacting alkyl halides with sodium.*

A synthesizing reaction of hydrocarbons was used by Adolphe Wurtz in 1855 as a method for producing paraffin hydrocarbons by using alkyl halides and sodium in ether. Along with the German chemist Wilhelm Rudolph Fittig (1835–1910), he developed a similar type reaction for synthesizing aromatic hydrocarbons. He also developed a way of synthesizing chemicals from ammonia by substituting the carbon radical C_2H_5 for one of the hydrogen atoms in ammonia (NH_3). By using this technique Wurtz was able to produce a variety of ammonia-related hydrocarbons. In 1860 Wurtz, in cooperation with August Kekule, formed a conference of the International Chemical Congress where he was scheduled to read a paper by the Scottish chemist Archibald Couper who had anticipated Kekule's method of forming the ring structure of the carbon atom. Wurtz delayed his presentation of the paper, while in the meantime Kekule published his theory for the ring structure of the carbon atom containing six carbon atoms in a paper and thus received credit for the discovery of the ring structure of the benzene molecule (C_6H_6). Couper became so angry with Wurtz for not presenting his paper that it resulted in his discharge from Wurtz's laboratory. Couper became despondent and never did any serious chemical research again.

Wurtz's father was a Lutheran pastor who supported his son Adolphe's study of medicine rather than theology. A good student, Wurtz was more interested in the chemistry involved in medicine and was promoted to the faculty of medicinal chemistry at the local university in Strasbourg. He held several positions at various universities in France but found their laboratories inadequate for his chemical research thus he built his own laboratory in his home. He had some difficulty in convincing the French government to support chemical research in which Germany was the leader. Adolphe Wurtz (he never used his given name Charles) was the founder of the Paris Chemical Society and served as its president on three occasions. He conducted research at several institutions, published many papers in his lifetime, and made important contributions to organic chemistry.

See also Couper; Kekule

WYNNE-EDWARDS' THEORY OF GROUP SELECTION: Biology: *Vero Cooper Wynne-Edwards* (1906–1997), England.

> *Different social behaviors are mechanisms for limiting a surplus of potential breeders beyond the quota that their habitat can carry.*

Wynne-Edwards was a keen observer of nature, particularly the roosting sites of the starling population in his home area. He noted that in addition to individual selection for breeding, there was group selection, which was an evolutionary construct. This group selection is based on the group's ability to control their rate of consumption of resources and to keep the breeding at a level that would benefit the group so it would not go extinct, whereas the individual selection of mates will generate populations of selfish individuals who overexploit the existing resources and will soon die out. He determined that one conflict with the idea of group selection is gene mutation in which the number of eggs laid may increase from two to six, and thus the increase in offspring may again exploit the available resources. Another conflict is immigration where new individuals who produce more than two eggs may upset the established balance of a two-egg group. He determined that other ecological factions could affect the established populations of a group such as weather (severe storms, freezing, drought, etc.), as well as human intervention.

Wynne-Edwards was one of the first ecologists, even before the discipline of ecology was a recognized field. He graduated with a degree in natural science (from which the science of ecology sprung) at Oxford University in 1927. He taught zoology at McGill University in Canada from 1930 to 1944. He returned to Britain and from 1946 to his retirement in 1974 was professor of natural history at Aberdeen University. His best-known book is *Animal Dispersion in Relation to Social Behavior* published in 1962 in which he expressed his theory of animal behaviors, such as territoriality, dominance hierarchies, groupings of flocks, and so forth as devices for controlling populations thus balancing the group and their resources. Others disputed his ideas. Some alternative explanations were altruism and population control as well as other ideas that led to the expansion of ecology and natural sciences related to sociobiology developed by Edward O. Wilson.

See also Buffon; Haeckel; Wilson (Edward Osborne)

Y

YALOW'S THEORY OF RADIOIMMUNOASSAY: Physics: *Rosalyn Sussman Yalow* (1921–), United States. Rosalyn Yalow shared the 1977 Nobel Prize for Physiology or Medicine with the French American researcher Roger Guillemin and Andrew Schally, the Polish-born medical researcher.

> *Using the technique of radioimmunoassay (RAI) to detect small amounts of radioactive hormones plus a known amount of antibody, and then mixing these with an unlabeled hormone, it is possible to accurately measure the amount of the nonradioactive hormones.*

By mixing a small amount of radioactive hormone with an unknown amount of another nonradioactive hormone provided a means to accurately detect and measure amounts of the nonradioactive hormone in amounts as small as one pictogram which is 10^{-12} grams. Using this technique that was discovered by Rosalyn Yalow and the American physician and scientist Solomon Berson (1918–1972), it was then possible for Roger Guillemin (1924–) and Andrew Schally (1926–) to detect the various elusive hypothalamic hormones, which was a breakthrough in the field of endocrinology.

Yalow graduated from Hunter College in 1941 where she developed an interest in physics. From there she worked as a secretary at Columbia University's College of Physicians and Surgeons with the belief that no top graduate school in the United States would accept a woman. During World War II, when many young, college-age men went off to war, she accepted an assistantship at the University of Illinois where she was the only woman in a department with four hundred men. The University offered assistantships to women rather than close the campus due to the absence of qualified male teachers. After taking advanced physics course, she graduated with a PhD in 1945. She then moved to the Bronx Veterans Administration Hospital to establish a program in radioisotope services where she perfected the technique of using small quantities of radioisotopes to trace and measure substances in blood, particularly in the study of insulin levels in diabetic patients. Her collaborator in this endeavor was Solomon Berson whose death in 1972 precluded his receipt of the Nobel Prize. Their radioimmunoassay techniques proved to be very valuable in detecting small amounts of hormones, vitamins, and enzymes that could not be detected by other means. Although this discovery was a huge success, she and Dr. Berson refused to obtain a patent for their discovery.

YANG'S THEORY OF NONCONSERVATION OF PARITY IN WEAK INTERACTIONS: Physics: *Chen Ning Yang* (1922–), United States. Chen Ning Yang shared the 1957 Nobel Prize in Physics with Tsung-Dao Lee.

> *The physical law of conservation of parity (symmetry) will break down during weak interactions of subnuclear elementary particles such as beta decay.*

Chen Ning Yang, a theoretical physicist, predicted in 1956 that the basic physical law of conservation of parity, first proposed by Eugene Wigner in 1927, would break down when the weak interactions (forces) related to the decay of elementary subnuclear particles were involved. *Parity* refers to the symmetrical quantum-mechanical nature of physical systems. *Parity conservation* refers to the basic physical concept of symmetry, which states that fundamental physical interactions cannot distinguish between right- or left-handedness, clockwise or counterclockwise, or mirror images of physical systems. In addition, for the conservation of parity, no distinction for the particle's orientation in space or the direction of time exists. Yang's theory predicted this concept was violated during the weak interactions of basic atomic elementary particles. These weak interactions are the fundamental forces that take place among elementary particles, including beta decay of nuclei, which produces neutrinos and electrons. Therefore, it is also known as *beta interactions*. These weak interactions are weaker than electromagnetic forces but stronger than gravitational interactions (the strong interaction involves the force that holds the nucleus together). Unlike electromagnetic and gravitational interactions, whose forces fall off as with the square of the distance and thus become less strong over long distances, the weak interactions fall off very rapidly, and thus are not effective beyond the size of the atom from which they originate. Yang and his collaborator, the Chinese-born American physicist Tsung-Dao Lee theorized that a subnuclear particle called a kaon would break down into two *pions,* which would maintain and conserve parity. But at times some of the kaons broke down in three pions, and thus, in this example of weak interactions, parity was not conserved (e.g., two odds and one even, or it could be described as two pions that spin clockwise while the other spins counterclockwise). This means the symmetry of left and right was not equal and electrons would exit the reactions in one direction more than in the other (nonsymmetrically). This resulted in the conclusion that parity would be conserved for electromagnetic and strong interactions but not for weak interactions. Chien-shiung Wu, who demonstrated that parity is not conserved in beta disintegrations, confirmed their theory. Physicists now believe there may be other antiparticles or energies that could account for this uneven symmetry. The concept of parity conservation for weak interaction of elementary subatomic particles is important for understanding the basic nature of matter.

See also Fermi; Feynman; Gell-Mann; Pauli; Wigner; Wu; Yukawa

YANOFSKY'S THEORY FOR COLINEARITY OF DNA AND PROTEIN: Biology: *Charles Yanofsky* (1925–), United States.

> *Gene sequences and protein sequences are colinear and thus changes in DNA sequences can produce changes in protein sequences, thereby controlling alterations in RNA's structure that permits RNA to act as a regulatory molecule in both bacterial and animal cells.*

After graduating in 1948 from City College of New York, Charles Yanofsky entered Yale University's graduate PhD program in microbiology. He spent three years as a postdoctoral candidate working on gene mutations. He discovered that one gene's mutation's effects are compensated by another so-called suppressor gene's mutation that will supply the missing enzyme in the first mutated gene, thus making the first mutated gene's harmful influence ineffective. Charles Yanofsky moved to Stanford University in California in 1958 as an associate professor in microbiology where he demonstrated that the linear sequence of amino acid molecules found in proteins are determined by the arrangement of nucleotide molecules found in DNA material. This provided the evidence for the assumption for the double helix structure of DNA proposed by James Watson and Francis Crick. Yanofsky received many awards for his research and has served as a professor of biology since 1961 at Stanford University.

See also Crick–Watson

YOUNG'S WAVE THEORY OF LIGHT: Physics: *Thomas Young* (1773–1829), England.

> *Light is transmitted through the aether as a wave front of beams that are both identical and singular.*

Thomas Young studied the functioning of the human eye. His theory that the lens of the eye changed shape to adjust to light and distance led him to explore the nature of light and how it traveled from one object to another. In the early nineteenth century, there were two conflicting theories of the nature of light. One claimed light was a stream (emission) of particles sent out by objects, which were received by the eye; the other stated that light consisted of minute standing waves and was transmitted by the aether. But the prevailing concept was the corpuscular theory for the emission of light, which claimed the polarization of light was possible only if light was a collection of single tiny particles originating from an object. This concept did not conform to Young's experimental evidence or to the mathematics of that time. Young proposed the transmission theory of light as a wave front of identical "beams" (not corpuscles), passing through a medium that he and others referred to as aether. Young experimented with a beam of light that he focused through two pinholes in a barrier to the path of a light beam. This produced two separate beams of light emanating from the pinholes on the other side of the barrier. These new standing wavelets exhibited two curved wave fronts whose matching crests showed up as alternate areas of light on a back screen (*see* Figure Y1).

Later, two narrow slits were used instead of pinholes. This phenomenon is known as *diffraction*, where the waves spread and bend as they pass through the small openings in

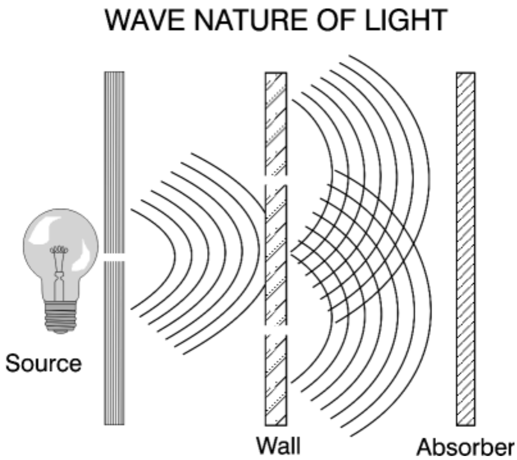

Figure Y1. Young's experiment demonstrated the wave nature of light. The light source passes through the hole in the first barrier, proceeds as a wave front to the second wall, where it passes through two holes, and emerges as two wave fronts that are recorded on the absorber wall. The light areas on the third wall will occur when the crest of the light waves are "in phase" and add to their brightness, while the dark areas are where the waves are "out of phase" and interfere with each other.

the barrier. At the point where the crests of the light wavelets were "matched," they intensified each other to form bright strips of light. Conversely, where the crests of the waves were not matched (interfere), they counteracted or blocked each other to form dark images. Diffraction (the splitting of the light beam into wavelets) and interference (the matching, or not matching, of the wavelet's crests) are basically the same phenomenon and now apply to all forms of electromagnetic radiation. Young's interference experiment was a classic demonstration proving the wave nature of light. It took some time for other physicists to understand the importance of Young's wave theory, but once accepted, it was used to exhibit why the different colors of the spectrum have different wavelengths. Using the wave front theory of light, Young and other physicists explained transverse wave propagation, the mechanical quality of the light medium, polarization, reflection and refraction, and other optical phenomena. His theory later assisted in determining the speed of light in air and water. His wave theory was augmented by the "quantum/photon" theory of light proposed by Schrödinger and Einstein, which resulted in the wave–particle duality of light.

See also Einstein; Fresnel; Hertz; Huygens; Maxwell; Schrödinger

YUKAWA'S MESON THEORY FOR THE "STRONG INTERACTION": Physics: *Hideki Yukawa* (1907–1981), Japan. Hideki Yukawa was the first Japanese citizen to be awarded the Nobel Prize for Physics in 1949.

Nuclei containing more than one positive proton must be held together by a force stronger than that of the protons' opposing positive charges.

Hideki Yukawa knew the "electroweak" force or the "weak interaction" that was involved in beta decay was much weaker than the force that binds nucleons of the nucleus together. Beta decay is the simplest type of radioactivity: a neutron decays into a proton, an electron, and what was later discovered to be a neutrino, which is considered massless (*see* Figure F2 under Fermi). Yukawa believed there must be a heavier particle that could fuse protons and neutrons within the nucleus of atoms. Using electromagnetic forces as an analogy, he applied quantum theory to predict that a stronger force was responsible for "binding" protons and neutrons in nuclei. The difference was that electromagnetic photons (visible light), which are considered massless, interact over infinite distances, whereas Yukawa's predicted nuclear binding "strong interaction" particle would be many times heavier than an electron and could react only over a distance less than the diameter of an atom (about 10^{-12}). In 1935 Yukawa predicted a new particle would bind nucleons in a nucleus. A few years later Carl Anderson confirmed the discovery of this new elementary particle. It was named the meson, and later *mu-meson*, which is now called a *muon*. Muons did not interact frequently enough with the nucleons (quarks, neutrons, and protons) to "glue" them together adequately. It was later discovered that the muon was a decay product of another particle with 265 times the mass of an electron. This heavier particle discovered by the British physicist Cecil Powell (1903–1969) in 1947 was first called the pi-meson and was later named the *pion*. The decay of the pion confirmed Yukawa's prediction for the "strong interaction" (force) that binds particles in nuclei.

See also Anderson (Carl); Fermi; Feynman; Gell-Mann; Pauli; Wigner; Wu; Yang

Z

ZEEMAN'S THEORY OF THE MAGNETIC EFFECT ON LIGHT: Physics: *Pieter Zeeman* (1865–1943), Netherlands. Pieter Zeeman shared the 1902 Nobel Prize in Physics with Hendrik Lorentz.

> *The spectral lines of light emitted from atoms are split into either two or three lines when the atoms emitting the light are subjected to a magnetic field.*

It had been known for some time that the light given off from burning chemical elements, when viewed through a spectroscope, would form distinct patterns of colors and dark lines. Sodium was the commonly used element for spectroscopic viewing. Its spectral lines are referred to as the "D-lines" due to their position in the electromagnetic spectrum. Pieter Zeeman, who undertook to verify Hendrik Lorentz's theory on atomic structure, set up a spectroscope to view these D-lines, placing an **electromagnet** between the scope and the sodium light source. He noticed that when the magnetic field was oriented perpendicular to the path of the light, the spectral lines were split into three distinct lines. When the magnetic field was oriented parallel to the light path, the lines were split into two images. This phenomenon, which is the splitting of spectral lines of a light source when passing through a magnetic field, became known as the *Zeeman effect*. Zeeman calculated the ratio of the electrical charge to the mass of the vibrating sodium ions, which proved it had a negative charge.

See also Bohr; Lorentz; Maxwell

ZENO'S PARADOXES: Physics: *Zeno of Elea* (c.490–430 BCE), Greece.

> *If space can be continually divided into an infinite number of units, it will take an infinite amount of time to pass through all these units of space. Therefore, motion is an illusion.*

Zeno of Elea, a pre-Socratic philosopher, devised paradoxes as arguments to contradict his philosophical opponents. The "theory" that motion cannot exist is only one of several of Zeno's paradoxes, based on the "dichotomy" that motion cannot exist because before it can reach where it is going, it must first reach a midpoint (half of its destination). He continued by stating that before this midpoint could be reached, it must reach one-fourth of its course, and before this, its one-eighth point, its one-sixteenth point, and so on. If one continues with this concept of motion, it can never proceed from where it starts. A similar but flip-side paradox is best explained by Zeno's story of the race between Achilles and the tortoise. Achilles and the tortoise start from the same point, but the tortoise is allowed to start first and reaches point A (half the distance of the race). Before Achilles can pass the tortoise, he must also reach point A, but by this time the tortoise has proceeded to point B. Now Achilles must run to point B, but the tortoise has proceeded to point C and so on. In a race so designed, Achilles will never catch the tortoise because as hard as he tries, he can cut the remaining distance only in half each time; thus the tortoise is always ahead and Achilles cannot win. This is an example of dividing the race into an infinite number of tasks, just as Zeno also stated that a line or space could be divided into an infinite number of units. This argument was used by Democritus to determine the atomic nature of matter by continually dividing a handful of soil into halves, over and over again, into an almost infinite number of times, until one tiny piece of matter so small it cannot be further divided remains—thus the atom. Zeno's paradox remained unsolved for two thousand years until it was explained by the use of calculus as the *convergence series*, an infinite series with a finite sum.

See also Atomism Theories

ZIEGLER'S THEORY OF STEREOSPECIFIC POLYMERS: Chemistry: *Karl Waldeman Ziegler* (1898–1973), Germany. Karl Ziegler shared the 1963 Nobel Prize in Chemistry with Giulio Natta.

> *The stereoregularity of a polymer depends on the catalyst used to prepare it, and once prepared, the polymer's stereochemistry does not change.*

Ethylene consists of long chains of thousands of ethylene molecules which, in turn, make up of thousands of polymer units of ethylene. Therefore, the stability of this long chain was unstable and tended to break causing the formation of branches that weakened the ethylene polymer plastics that had a boiling point just above 212° F. Ziegler used a group of catalysts (usually metallic ions of titanium or aluminum) that prevented branching of the chains. By using these catalysts, much stronger plastics, including ones that could be kept in water without softening, can be manufactured. Ziegler mainly studied the polymer known as polyethylene, while Giulio Natta used a similar system to study other polyalkenes, such as isotactic, syndiotactic, or atactic forms of methyl polymers. The $TiCl_4$ and VCl_4 catalysts are used to convert propene to isotactic polypropylene and syndiotatic polymers. The Ziegler–Natta catalyst was a major development in understanding the chemistry and the production of various polymerization processes and their products, such as, plastic bottles for milk and beverages, and household cleaners, toys, components for appliances, moulds, to name a few.

ZINN'S CONCEPT OF A "BREEDER REACTOR": Physics: *Walter Henry Zinn* (1906–2000), United States.

When irradiated by neutrons, uranium-238 can be converted into fissionable plutonium-239.

It was known for some time that when neutrons were slowed down, they could penetrate the nuclei of uranium, thus causing the uranium nuclei to split into nuclei of lighter elements while collectively giving off great amounts of energy. Walter Zinn and his mentor, Leo Szilard, demonstrated that a small mass of the split uranium nucleus was converted into energy, as predicted by Einstein's formula, $E = mc^2$. At the beginning of World War II, Zinn worked with Enrico Fermi on the Manhattan Project to build the first nuclear pile. Zinn was the person who slowly pulled the control rods from the pile to allow more neutrons to interact with purified uranium. At the time, no one knew if it would work or blow up. This pile was successful and demonstrated that a sustainable fission reaction was possible, which led to the first "atomic" bombs. Zinn was also in charge of dismantling the reactor. In 1951 Zinn developed the first breeder reactor that used neutrons emitted from the core of an atomic reactor to change a blanket of U-238 surrounding the core into plutonium-239 (Pu-239). Pu-239, first identified in 1940 by Glenn T. Seaborg, who used a cyclotron, is fissionable with a long half-life. About 0.66 of a pound is needed to reach a critical mass and become a nuclear bomb, which is about one-third as much required of the less plentiful U-238. Pu-239 is highly radioactive but relatively easy to produce and can be used in lightweight reactors to produce heat and electricity.

See also Fermi; Seaborg; Szilard

ZUCKERANDL'S THEORY FOR MEASURING THE RATE OF EVOLUTION: Biology: *Emile Zuckerandl* (1922–), United States.

The differences in the hemoglobin chains in mammals can be used as a "clock" to measure the time spans of the evolution of species.

While comparing the amino acids in the hemoglobin of the blood of different animals, Emile Zuckerandl discovered that out of the 146 amino acids in one of the human hemoglobin chains, only one was different from the gorilla. However, there were more differences in the amino acids for other mammals. He used this concept to formulate a "mean" difference of twenty-two hemoglobin chains for all mammals. He then considered the time during which these animals "split" off from a common ancestor to be about eighty or ninety million years, surmising it takes approximately seven or eight million years for evolution to change one pair of amino acids. This theory was improved and became valuable for future biologists to estimate the rate of organic evolution.

See also Darwin; Waddington; Wilson (Allan)

ZWICKY'S THEORY FOR SUPERNOVAS AND NEUTRON STARS: Astronomy: *Fritz Zwicky* (1898–1974), United States.

Supernovas, which are distinct from novas, are brilliant stellar explosions that collapse into neutron stars under their own gravitational force.

Fritz Zwicky was the first to theorize that supernovas were different from other bright objects in the sky (*nova* means "new" in Latin). His theory stated that supernovas were stellar explosions that produced great brightness. Zwicky claimed that only about two or three supernovas are ever discovered during each thousand-year period. He determined that supernovas have a brightness that is about fourteen to fifteen times that of the sun, making them visible at the great distances where galaxies are found. He also calculated that when a supernova burned out and there was no longer radiation to maintain its size and brilliance, it would collapse. According to the law of gravity, it would attract all of its mass into a dense core and end its existence as a neutron star. A neutron star is as massive as a regular star, but it is only 7 to 9 miles in diameter. In other words, its density is so great that a teaspoonful would weigh many tons. Years later Zwicky's prediction for supernovas was borne out when the existence of superdense neutron stars was discovered. His work with supernovas resulted in theories of galaxy evolution, including galaxy clusters and super-clusters of many galaxy clusters, which indicate that distant matter in the universe may not be evenly distributed.

See also Baade; Hubble; Rossi

Glossary

absolute temperature. In theoretical physics and chemistry, refers to the Kelvin scale, specifically for absolute zero which is $-273.13°$ Celsius or $-459.4°$ F. This is the temperature at which all matter possesses no thermal energy and at which all molecular motion ceases, with the exception of molecules vibrating in place without moving. It has never been reached.

AC. Abbreviation for *alternating current*. Electric current in a circuit that reverses its direction at repeated intervals and that was discovered by Nikola Tesla.

acid. A substance that releases hydrogen ions when added to water. Strong acids are sour tasting, turn litmus paper red, and react with some metals to release hydrogen gas.

adiabatic. Refers to a reversible thermodynamic process in which there is no transfer of heat into or out of a closed (isolated) system.

adsorption. Adherence or collection of atoms, ions, or molecules of a gas or liquid to the surface of another substance, called the *adsorbent*; for example, hydrogen gas collects or adsorbs to the surface of several other elements, particularly metals. An important process in the dyeing of fabric.

aether. Early scientists assumed a "medium" called aether, which in Greek mythology typifies the upper air, occupied all space, and thus it was believed to be required for the transmission of electromagnetic waves. Also referred to as *ether*.

agar. A gelatinous substance extracted from a specific species of red marine algae. Used mainly as a gelling agent in bacterial culture media. Also an ingredient in creams, ointments, and commercial laxatives.

AIDS. Acquired Immune Deficiency Syndrome; disease that compromises the immune system through persistent opportunistic infections and malignancies and is believed to be caused by the human immunodeficiency virus (HIV).

albedo. In astronomy, *bond albedo* is the fraction of the total light incident that celestial bodies (e.g., planets, asteroids, satellites) reflect back to space in all directions. In the field of optics, *normal albedo* (also called normal reflectance) is the measurement of the fraction of light or electromagnetic radiation that is reflected by any surface that is viewed vertically.

alchemist (alchemy). A forerunner of modern chemistry (chemists) practiced from approximately 500 BCE thru the sixteenth century. It had a twofold philosophy: the search for and use of the philosophers' stone to transmute base metals into gold and prepare and perfect medicine for people, called the *elixir vitae*.

alkaloid. In organic chemistry, a basic nitrogenous compound obtained from plants, soluble in alcohol and insoluble in water (e.g., morphine, nicotine, caffeine, cocaine).

allele. The shortened form of the term *allelomorph*. An alternative, and possibly a mutational, form of the same gene. For instance, in a diploid cell, there are two alleles (from each parent) of one gene, one of which is dominant, the other recessive. The dominant gene determines the particular characteristics displayed by the organism. Each allele has a unique nucleotide sequence.

alpha particle. A nucleus of a helium atom (H^{++})—that is, two positive protons and two neutrons, without any electrons. Alpha particles, along with beta and gamma particles, constitute the three basic forms of radiation resulting from nuclear decay.

altimeter. An instrument that is used to measure the altitude of an object above a fixed level (e.g., sea level or at the top of a mountain). A *pressure altimeter* (aneroid barometer) measures air pressure from a stationary position outside an aircraft. A *radar or radio altimeter* measures the height of the aircraft above ground level during the landing process.

amino acid. An organic compound comprising both an amino group (NH_2) and a carboxylic acid group (COOH). They are polymerized to form proteins and peptides. Amino acids occur naturally and also have been synthesized in laboratories. It is believed that products of a naturally occurring synthesis of amino acids may be the buildings blocks of life.

amniocentesis. The surgical removal of a sample of amniotic fluid from a pregnant woman. The chemical analysis of the fluid can determine the sex of the fetus, as well as genetic disorders such as Down's syndrome, developmental disorders such as spina bifida, and a number of biochemical and/or chromosomal abnormalities.

amplifier. A device capable of increasing the level of power or the magnitude, for example, an electric current that uses a transistor or an electron tube with an electric signal that varies with time and does not distort the shape of the electrical waves.

anode. The positively charged electrode in an electrolytic cell, electron tube, or storage battery; the collector of electrons.

antibody. A blood serum protein, sometimes occurring normally or generated in response to an invading antigen, that specifically reacts with a complimentary antigen to produce immunity from a number of microorganisms and their toxins.

antimatter. *See* antiparticle.

antineutrino. The antiparticle to the neutrino. *See also* antiparticle.

antiparticle. A subatomic particle—a positron (positive electron), antiproton, or antineutron—with the identical mass of the ordinary particle to which it corresponds but opposite in electrical charge or in magnetic moment. Antiparticles make up antimatter, the mirror image of the particles of matter that make up ordinary matter as we know it on Earth. This is a theoretical concept devised to relate relativistic mechanics to the quantum theory.

antiproton. The antiparticle to the proton. *See also* antiparticle.

aperture. An opening (i.e., hole or slit) through which light waves, radio waves, electrons, or radiation can pass. This may be the adjustable opening on optical instruments (e.g., cameras and telescopes).

aplanatic lens. A lens whose surfaces are not segments of a sphere. It is used to correct imperfect focusing called *spherical aberration*.

asteroid. Derived from the Greek word *asteroeidēs*, which means "starlike." They are small bodies that revolve around the sun. They are sometimes called small "planetoids," and when they become fragmented and land on Earth they are considered meteorites. Most asteroids are found in a planetary orbit called the *asteroid belt*, located between the orbits of Mars and Jupiter.

atmosphere. Also known as *ATM* for standard atmosphere. A unit of pressure that is equal to 101.325 pascals which is the air pressure that is measured at mean sea level. The actual atmospheric pressure fluctuates around this number, but the unit is used to express pressures that are in excess of standard atmospheric pressure, such as those employed during high-pressure chemical transactions. (The *pascal* is named after the French mathematician Blaise Pascal and refers to a unit of pressure equal to one newton per square meter.)

atomic number (proton number). The number of positively charged protons found in the nucleus of an atom, upon which its structure and properties depend. This number determines the location of an element in the Periodic Table. For a neutral atom the number of electrons equals the number of protons.

atomic weight (atomic mass). The total number of protons plus neutrons in an atom.

AU (astronomical unit). The average distance of Earth from the center of the sun—approximately 93 million miles, or 150 million kilometers.

autocatalytic. The theoretical process where primordial organic molecules may have replicated themselves in early prebiotic environments.

autonomic. Independent, spontaneous, or involuntary. Relates to the autonomic nervous system and autonomic reflex system in vertebrates and other animals, as well as the autonomic movement in plants.

autopoiesis. The self maintenance of an organism.

axiom. An assumption upon which a mathematical theory is based.

baryons. Also known as heavy particles. They are the family of heavy subatomic particles that are made up of three quarks and that include protons and neutrons. Baryons are strongly interacting fermions that experience the strong nuclear force.

base. An alkali substance that reacts with (neutralizes) an acid to form a salt, for example, $4HCl + 2Na_2O \rightarrow 4NaCl + 2H_2O$ [hydrochloric acid + sodium hydroxide yields sodium chloride (table salt) + water].

biosynthesis. The natural synthesis (fusion) of an organic chemical compound by living organisms.

birefringence. Also known as double refraction. The splitting of a beam of ordinary light into two beams of light that travel at different velocities by a medium, such as calcite or quartz. Also defined as the difference in the indices of refraction of a crystal.

black holes. Theoretically, they are thought to be vortex areas in space where massive stars have collapsed, creating such great gravity that not even light can escape into space.

bolides. Two or more parts of a large meteor formed when the meteor, usually called a *fireball*, produces bright streaks of light and splits. Called bolides after the Greek word *bolis*, which means "missile." A loud hissing noise can sometimes be heard as one of these large meteors passes through the atmosphere.

bonding (chemical). Electrostatic force that holds together the elements that form molecules of compounds. This attractive force between atoms is strong enough to hold the compound together until a chemical reaction causes the substance to either form new bonds or break the bonds that form the molecule. *See also* covalent bond; ionic bonding.

bosons. One of two main classifications of subatomic particles, they are weak "force" particles, (photons, pi mesons, gluons, positive W and negative W particles, neutral Z particles, gravitons). The other main classification of subatomic particles is the fermion.

calorimeter. An instrument that measures thermal activity (heat) generated in or emitted by chemical reactions that result in a change of state of the involved chemical(s).

calx. Calcium oxide (CaO). The crumbly, white, water-soluble solid residue that is left after the calcination of calcium carbonate limestone that results in the removal of all the carbon dioxide from the mineral. Also called caustic or burnt lime; chalk. It is used in the pulp and paper industries and as a flux in the manufacture of steel.

capacitor. A storage device (condenser) for static electricity, consisting of two or more metal surfaces (conductors) separated from each other by a dielectric. It stores the electrical energy and impedes the flow of direct current. *See also* Leyden jar.

catalyst. Any substance that affects the rate of a chemical reaction without itself being consumed or undergoing a chemical change. Platinum/palladium pellets in automobile catalytic converters are chemical catalysts. A biological catalyst (e.g., an enzyme) affects chemical reactions in living organisms.

catastrophism. In biology and geology, the idea that catastrophic events that have occurred in the past (e.g., earthquakes and volcanoes, meteor impacts, and major climate changes) radically altered Earth's surface and/or biological processes.

cathode. A negatively charged electrode or plate, as in an electrolytic cell, storage battery, or an electron tube similar to a TV. Also, the primary source of electrons in a cathode ray tube such as the Crookes tube.

Cepheids. A population of giant yellow stars that pulses regularly by expanding and contracting due to the changes in their surface temperatures, resulting in an oscillation of their luminosity that ranges from 10^3 to 10^4 greater than the sun. The importance of a Cepheid variable is its function as a "standard candle" or candela (indicator) to determine its distance from Earth, thus an essential component in celestial mapping. Also called *Cepheid variables*.

chemical reduction. A chemical reaction in which the oxidation number (oxidation state) of atoms is changed. Also called reduction/oxidation reaction or redox for short.

chiral bag model. In the field of quantum chromodynamics (QCD), it refers to one of several models of the nucleon, which is a general term for either the neutron or proton as a constituent part of the nucleus. The nucleon is made up of three quarks, but the actual equations of motion for QCD are unknown. The chiral bag model, a composite of two other models, is a theoretical attempt to address the asymmetry of the nucleon.

chloroplasts. Chlorophyll-containing organelles (cell plastids) found in abundance in plant cells that undergo photosynthesis.

chromatography. Any of a group of techniques used to separate complex mixtures (i.e., vapors, liquids, or solutions) by a process of selective adsorption (not to be confused with absorption), the result being that the distinct layers of the mixture can be identified. The most popular techniques are liquid, gas, column, and paper chromatography.

chromosomes. The complex, DNA-containing, threadlike material inside the nuclei of the cells of living organisms that determines hereditary characteristics of that organism.

chromosphere. The transparent, gaseous (mainly hydrogen) layer of the sun's atmosphere that rests on and completely surrounds the photosphere. It is approximately several thousand miles thick and acts as a thermal buffer zone between the photosphere and the coronal layer. Temperatures range from 6,000°C where it merges with the photosphere to 20,000°C at the region below the corona.

cloud chamber. A device for detecting the paths of high-speed particles as they move through a chamber filled with air or gas which is saturated with water vapor. The device is fitted with a piston that, when moved outwardly, affects the expansion of the gas and the cooling of the vapor. A fog or cloud of minute droplets then forms on any nuclei or ions present in the chamber. Also known as the *Wilson cloud chamber*.

codons. A sequence of three adjacent nucleotides within a molecule of $_{m}$RNA (messenger RNA) that carries the genetic code (*triplet code*) of one amino acid during protein synthesis. It is the basic unit of the genetic code.

coke. The residue produced after bituminous coal or other carbonaceous materials, such as petroleum or pitch, are heated to extremely high temperatures in the absence of air. Primarily consisting of carbon, it is used as a fuel in blast furnaces.

comet. A nebulous celestial formation consisting of rocks, ice, and gases. Comets are composed of three main parts: the *nucleus*, which is the center made of rock and ice; the *coma*, which is composed of the gases and dust that form around the nucleus as it evaporates; and the *tail*, which is made up of the gases and spreads out from the coma.

compound. A substance in which two or more elements are joined by a chemical bond to form a substance different from the combining elements. The combining atoms do not vary their ratio in their new compound and can only be separated by a chemical reaction, not a physical force. *See also* bonding.

conductor. Substances that allow heat or electricity to flow through them.

cosmogony. The astrophysical study of the origin and evolution of the universe.

cosmology. (cosmos, cosmological). The study of universe on the smallest and largest of scales in terms of time, space, and the makeup of the universe. It includes theories about the origin of the universe and everything in it, the evolution of the universe from past to present to future, and the structure of the universe and its celestial bodies at various stages of their evolution.

covalent bond. Sharing of electrons by two or more atoms to form a pair of electrons. This type of bonding always produces a molecule. Also known as *electron pair bond*. *See also* bonding.

critical mass. The minimum mass of fissionable material (U-235 or PU-239) that will initiate an uncontrolled fission chain reaction, as in a nuclear (atomic) bomb.

critical temperature. The temperature above which a substance cannot be converted from the liquid to the gaseous state or vice versa, regardless of the pressure applied. Also, the temperature at which a magnetic material will lose its magnetism.

cryogenics. Study of the behavior of matter at very low temperatures below −200°C. The use of the liquefied gases (oxygen, nitrogen, hydrogen) at approximately −260°C is standard industrial practice.

cyclotron. A particle accelerator made up of two hollow cylinders (similar to two opposing D structures) that are connected to a high frequency alternating voltage source in a constant magnetic field. The charged particles, which are injected near the midpoint of the gap between these two hollow cylinders, are then accelerated in a spiral path of increasing expanse so that the path traveled by these accelerated particles increases with their speed where a deflecting magnetic field deflects them to a target. *See also* particle accelerator.

daltons. Named after English chemist John Dalton, it is an arbitrarily defined unit that is used to express the masses of atoms, molecules, and nuclear particles. The standard (dalton) is the unit of mass equal to one-twelfth the mass of ^{12}C. Also known as atomic mass unit (*AMU*).

dark matter. Nonluminous matter that is assumed to be present in the Milky Way and other galaxies that explains the motions of the stars and clouds of gases in those galaxies. Cosmological theory states that such dark matter makes up over 90% of all matter in the universe and must exist to achieve the critical density necessary to close the universe.

DC. Abbreviation for *direct current*. Electric current that flows in only one direction.

declination. In astronomy, it is the angular distance north (positive) or south (negative) of the celestial equator, that is, the circle formed on the celestial sphere in the same plane as Earth's equator. In navigation, it is the arc between the equator and the point measured on a great circle perpendicular to the equator.

dendrochronology. The study of tree rings as a dating method for events and conditions over a limited period time. It is based on the number, width, and density of annual rings of older trees that have been cut into cross sections. Using trees such as Douglas fir and white pine enables scientists to establish a master tree index that can date, rather accurately, both events and climatic conditions over the past several thousand years.

deterministic/determinism. The doctrine that espouses that all phenomena are causally determined by prior events. It has also been stated as the relationship between a cause and its effect, particularly natural phenomena, or as the hypothesis stating a set of precisely determined conditions will always repeat the same effect, or that an event cannot precede its cause. Also known as *causality*.

diastolic. Refers to the rhythmic relaxation and dilation of the heart's chambers, particularly the ventricles. The diastolic reading on a blood pressure monitor that records the lowest arterial blood pressure during the time the ventricles fill with blood.

diphtheria. An acute infectious disease of humans that is caused by the growth of the *corynebacterium diphtheriae* bacillus on a mucous membrane, especially in the throat and nose and characterized by respiratory difficulty and high fever. Prior to the discovery of a vaccine in 1923, and the development of various antibiotics that are successful in treating the disease, diphtheria had a high mortality rate, especially among children.

dipole. A pair of magnetic poles or electric charges of equal magnitude but with opposite polarity that are separated by a small distance.

DNA. Abbreviation for *deoxyribonucleic acid*. The complex ladder-like, double-stranded nucleic acid molecule present in chromosomes that forms a double helix of repetitive building blocks and shapes the inherited genetic characteristics of all living organisms, with the exception of a small number of viruses.

Doppler effect. The apparent change or shift in the observed frequency of a sound or electromagnetic wave due to the relative movement between the source and the observer. The same principle applies when determining the distance of stars in the galaxy. The Doppler frequency or shift is based on the color shift (frequency of light) related to the star's velocity. The light frequency for a star receding from Earth is redder (longer wave lengths) than a star approaching Earth, which emits a blue light (shorter wave length).

ecology. The scientific study of the interrelationships of organisms to each other and their physical, chemical, and biological environments.

electrolysis. A process in which an electric current is passed through a liquid, known as an electrolyte, producing chemical changes at each electrode. The electrolyte decomposes, thus enabling elements to be extracted from their compounds. Examples are the production of chlorine gas by the electrolysis of sodium chloride and the electrolysis of water to produce oxygen and hydrogen.

electrolyte. A compound that, when molten or in solution, will conduct an electric current. The electric current decomposes the electrolyte.

electromagnet. A strong magnet composed of a wire coil that is wrapped around a soft-iron core through which a current of electricity is passed and which becomes demagnetized when the flow of electric current is suspended.

electron. An extremely small, negatively charged particle that moves around the nucleus of an atom. The interaction of the electrons of atoms is the chemistry of Earth's elements.

electrophoresis. A method for separating and analyzing colloidal particles in a stable liquid which is under the influence of an electric field. The movement of the colloids is the result of Coulomb's law: *two bodies charged with the same sort of electricity will repel each other in the inverse ratio of the square of the distance between the centers of the two bodies*.

electroscope. An apparatus that detects the presence and signs of minute electrical charges using a process of electrostatic attraction and repulsion.

empirical. Relates to actual observation, practical experience, and experimentation rather than scientific theory.

endosymbiosis. Refers to the process responsible for the origination of a new organism, namely the fusion of two independently evolved organisms. One, called the *host,* and the other, called the *endosymbiont*, become a tightly joined system that eventually evolves into just one organism. In many cases, but not all, endosymbiosis is obligate, that is, neither organism can survive without the other. Often there is no benefit to the host organism or the endosymbiont is harmful to the host or the host to the endosymbiont. It is a controversial theory for the formation of life, specifically that some inorganic chemicals combined to form organic molecules.

energy. The capacity to do work. Heat and work are forms of energy and are interchangeable. Some examples of energy are heat, light, sound, radioactive, and mechanical.

entropy. Disorganization, randomness. In thermodynamics, it is the function of the system where the amount of heat transfer introduced in a reversible process is equal to the heat that is absorbed by the system from its surroundings, divided by the absolute temperature of the thermodynamic system.

enzyme. Any of a number of proteins or conjugated proteins which are produced by living organisms that act as biochemical catalysts in those organisms.

equilibrium. A state or condition in which the influences of energy forces and related reactions are canceled by each other, the result of which is a balanced stable, and unchanging system. *Thermal equilibrium* is said to occur when no heat exchange has taken place within a body or between the body and its surroundings.

equinox. One of two points or moments on the celestial sphere when the center of the sun intersects the celestial equator, either in a north or southbound direction.

ether. *See* aether.

eugenics. The genetic principles of heredity to improve a species, most often associated with breeding or engineering of a "superior" race of humans while discouraging the breeding of those considered "inferior." Animal and plant breeding as well as genetic counseling might be considered less extreme applications of eugenics.

eukaryotic. Describes the state of a cell (eukaryote that makes up all living things except bacteria and cyanobacteria) containing a definitive nucleus, in which nuclear material is surrounded by a membrane and cytoplasm-containing organelles. Along with prokaryotes, they are the two major groups into which organisms are divided.

fermion. A subatomic particle (electron, proton, or neutron) having odd half-life integral angular momentum, which obeys the Pauli exclusion principle: *no more than one in a set of identical particles may occupy a particular quantum state.*

fission. The splitting of an atom's nucleus with the resultant release of enormous amounts of energy and the production of smaller atoms of different elements. Fission occurs spontaneously in the nuclei of unstable radioactive elements, such as U-235 and Pu-239, and is used in the generation of nuclear power, as well as in nuclear bombs.

fluorescent. Consisting of a gas-filled tube with an electrode at each end. Passing an electric current through the gas produces ultraviolet radiation which is converted into visible light by a phosphor coating on the inside of the tube. This emission of light by the phosphor coating is called fluorescence.

forensics. Relates to public discussion or debate, particularly in legal proceedings, concerning engineering practices, medical evidence, chemical studies, and so forth where the findings are presented as legal evidence in a court of law.

fractal. An irregular or fragmented geometrical shape whose intricate structure is such that, when magnified, the original structure is reproduced (self-similarity). Fractals are important in the study of certain branches of physics, as well as in chaos theory and computer-generated graphics.

fusion. An endothermic nuclear reaction yielding large amounts of energy in which the nuclei of light atoms (e.g., forms of heavy hydrogen, such as deuterium or tritium) join or fuse to form helium (e.g., energy of our sun or the hydrogen bomb). The opposite of fission.

galaxy. A huge grouping of millions, or even billions, of stars held in one of several shapes by their mutual gravity. There are elliptical, irregular, and spiral galaxies.

galvanometer. An instrument that measures a small electrical current using mechanical motion derived from the electrodynamic or electromagnetic forces produced by the current.

gene. The basic unit of hereditary material that is composed of a sequence of nucleotides of a section of DNA or RNA molecules. The sequence of nucleotides determines the structure of amino acids in proteins, which is fundamental to all other biological processes. Genes, individually or in groups, determine inherited characteristics.

genetic drift. In population genetics, it is the statistical effect that results from the random fluctuations of gene frequencies from generation to generation, primarily in small populations. In other words, chance alone can have a profound effect, thus the concept of genetic drift.

genetics. The science of biological heredity and the mechanisms by which characteristics are passed along to succeeding generations.

genomes. The complete hereditary information encoded in the DNA (or for some viruses, in the RNA) of an organism of species. In other words, all the genes are contained in a single set of haploid chromosomes. During reproduction, each parent contributes its genome to its offspring.

geomagnetism. Refers to Earth's magnetism and, in a broader sense, the magnetic phenomena of interplanetary space.

glaciation. The alteration of the surface of Earth by passage of glaciers, mainly by erosion or deposition.

global warming. The increase in global temperatures reportedly augmented by the emission of industrial gases, along with other natural air pollutants, that traps heat from the sun. A natural cloud cover acts as an "insulating blanket" which keeps the heat of Earth and the lower atmosphere from radiating into the outer atmosphere and on into space. Scientists on both sides of the issue continue to debate whether there is increasing evidence that the addition of pollutant clouds into the atmosphere has increased Earth's temperature with the potential to cause climatic, often catastrophic, changes in the environment. Also referred to as the *greenhouse effect*.

gluon. A hypothetical, massless, neutral elementary particle that carries the strong force (interactions) that binds quarks, neutrons, and protons together. Gluons can also interact among themselves to form particles that consist only of gluons without quarks and are called *glueballs*.

graviton. A hypothetical (not yet discovered) carrier particle presumed to be the quantum of gravitational interaction, having a mass and charge of zero and a spin of 2.

ground state. The lowest stable energy state of a system of interacting elementary particles.

gutta-percha. It is a natural polymer derived from the milky, thermoplastic substance that is obtained from gutta-percha trees (genera *Palaquium* and *Payena*) found in Malaysia. It is an excellent electrical insulator, particularly in submarine cables. Also used in golf balls and waterproofing products.

hadron. An elementary particle, part of the largest family of elementary particles, that has strong interactions, usually producing additional hadrons during high energy collisions.

half-life. The time required for one-half of the atoms of heavy radioactive elements to decay or disintegrate by fission into lighter elements.

halogens. Electronegative monovalent nonmetallic elements of Group 17 (VIIA) of the Periodic Table (fluorine, chlorine, iodine, bromine, astatine). In pure form, they exist as diatomic molecules (e.g., Cl_2).

heliocentric. Refers to belief that the sun is the center of the solar system or universe.

homeostasis. The physiological state of equilibrium within an organism. In other words, its chemical composition, as well as other internal functions, are in balance (e.g., body temperature, acid-base balance).

hominid. Member of the mammal family of which homo sapiens is the only surviving species.

hominoid. Manlike; an animal that resembles a human. (Humans and anthropoid apes are usually included in the superfamily commonly referred to as hominoids.)

homologous. In evolutionary theory, refers to the structural relationship between the physical parts of different species or organisms due to evolutionary development (e.g., the wing of a bird and the pectoral fin of fish; the flipper on a sea lion and the arm on a primate).

humoral theory. Pertains to the practice of medicine, primarily in the Middle Ages, whereby the body was governed by four principle humors or fluids (blood, phlegm, choler, and black bile). These were present in varying proportions in each person, the balance of which was essential for continued good health. If any of these four "humors" were out of balance, a procedure (e.g. blood letting) was performed by the physician in an effort to restore "balance."

hydrostatic. The study of liquids at rest (e.g., liquids contained in dams, storage containers, and hydraulic machinery).

hypotenuse. In a right triangle, the side opposite the right 90° angle.

impedance. In electronics, it is a term that describes a portion of the overall opposition of a circuit to a sine wave of alternating current, that is, how much the circuit impedes the flow of current. The term, which is measured in ohms **Ω**, is often used interchangeably with the term "resistance" when referring to simple circuits that have no capacitance or inductance. However, impedance is more complex and includes the effects of capacitance and inductance. Impedance varies with frequency, whereas the effect of resistance is constant regardless of frequency.

incidence. In optics, it refers to the incidence angle (also angle of incidence) that is formed between a beam or a ray on a surface and the perpendicular line at the point of incidence (arrival).

inclination. The angle between a reference plane and the axis of direction, that is, the deviation from the vertical to the horizontal. In astronomy, it is also called *magnetic inclination* or *magnetic dip*. The dip angle of Earth's magnetic field.

inductor. A passive electrical device, such as a coil of copper wire wrapped around a ferromagnetic material, that introduces electromagnetic force (inductance) into an electrical circuit.

in vitro. Meaning "in glass" in Latin. Refers to an observable biological reaction that occurs under artificial conditions outside of a living organism, usually in a test tube or a petri dish.

ion. An atom or a group of atoms that have gained or lost electron(s) and thus have acquired an electrical charge. The loss of electrons gives positively charged ions. The gain of electrons results in negatively charged ions. If the ion has a net positive charge in a solution, it is a *cation*. If it has a net negative charge in solution, it is an *anion*. An ion often has different chemical properties than the atoms from which it originated.

ionic bonding. Donating of electrons from one element to another element, forming positively and negatively charged ions respectively. The electrostatic attraction between the oppositely charged ions constitutes the bond. Also known as *electrovalent bond*.

ionization. The chemical process for producing ions in which a neutral atom or molecule either gains or loses electrons, giving it a net charge, thus becoming an ion.

irrational numbers. Any real number that is not the quotient of two integers. They are usually algebraic (roots of algebraic equations) or transcendental numbers.

isomer. In chemistry, chemical compounds with the same molecular composition but with different chemical structures. For example, butane has two isomers, C_4H_{10} *and* $C_2H_4(CH_3)_2$. In nuclear physics, isomers refer to the existence of atomic nuclei with the same atomic number and the same mass number but different energy states.

isomerism. Refers to the condition whereby certain chemical compounds have the same molecular formulae but different molecular structures.

isostasy. The theoretical gravitational equilibrium existing in the earth's crust. If there is a disturbance on the surface of Earth (e.g., erosion or glacier movement, which is also referred to as deposition), there are counterbalancing movements in Earth's crust. The areas of deposition will sink, whereas the areas of erosion will rise. The same counterbalancing effect also occurs in Earth's oceans as the lack of density in ocean water is compensated by an excess density in the material under the ocean's floor.

isotopes. Atoms of the same element with different numbers of neutrons in their nuclei. All atoms of an element always contain the same number of protons in their nuclei. Thus, their proton (atomic) number remains the same. However, an atom's nucleon number, which denotes the total number of protons and neutrons, can be different. These atoms of the same element with different atomic weights (mass) are called *isotopes*. Isotopes of a given element all have the same chemical characteristics (electrons and protons), but they may have slightly different physical properties.

kaon. An elementary particle that is a subclass of the hadrons. Mesons consist of quark—antiquark pairs. They have zero spin, a nonzero strangeness (quantum) number, and a mass of approximately 495 MeV. It is the lightest hadron to contain a strange quark. Also known as a *K meson* in particle physics.

kinetic energy. Energy association with motion.

latitude. Angular distance of a point on Earth's surface measured along a meridian from the equator (zero latitude) north or south to the poles, which are at 90°N or 90°S.

lepton. In particle physics, any light particle. Leptons have a mass smaller than the proton mass and do not experience the strong nuclear force. They interact with electromagnetic and gravitational fields and essentially interact only through weak interactions.

Leyden jar. An early and improved form of *capacitor* (condenser). Metal foil was placed on both the inside and outside of the glass jar, allowing the glass to act as a dielectric or nonconducting substance to separate the electrical charges. A charge of stored static electricity occurred as the wire touched the inside foil, which was fed through the insulating cork on the top of the jar. A circuit was completed when the wire conducted the electricity to the foil on the outside of jar, or a spark jumped to a finger if it was brought near the wire exiting the jar. *See also* capacitor.

libration. The very slow oscillatory rotation, either real or apparent, of a satellite that does not possess enough energy to make a full rotation as seen from a larger celestial body around which it revolves. An example: the libration's of Earth's moon that enables 59% of its surface to be observed on Earth despite its synchronous rotation.

logarithm. A mathematical method developed in the sixteenth century that simplified the multiplication and division processes for large sums by using exponents of the number 10, which are called *logarithms* (shortened to *logs*). Multiplication is reduced to addition; division reduced to subtraction. For example, the log of 100 written as (10^2) is 2; the log of 1000 written as (10^3) is 3. Thus, multiplying 100 × 1000 can be facilitated by adding their logs which since the sixteenth century have been recorded in a series of tables of logarithms. The answer is 100,000 or log (10^5). In advanced mathematics, logarithmic tables have been formulated to deal with computations involving far more complex infinite numbers.

macromolecules. Very large molecules composed of many relatively simple structural units, each of which consists of several atoms that have bonded together. Examples are polymers (natural and synthetic) and proteins.

magnet. A body or an object that has the ability to attract certain substances (e.g., iron). This is due to a force field causing the movement of electrons and the alignment of the magnet's atoms.

magnetic moment. In physics, the ratio between maximum torque which is exerted on a magnetized body, electric current-carrying coil, or magnetic domain, including nuclei, and the strength of that magnetic domain or field. Also called *magnetic dipole moment*.

magnetohydrodynamics. In physics, the study of motion or dynamics of electrically conducting fluids (plasmas, ionized gases, liquid metals) and their interactions with magnetic fields. Also known as *hydromagnetics* or *magnetofluid dynamics*.

magnetosphere. The comet-shaped regions surrounding Earth and the other planets where the charged particles are controlled by the planet's own magnetic field rather than the sun's. Earth's geomagnetic field is believed to begin at an altitude of about 100 kilometers and extends to the far-away borders of interplanetary space.

manometer. A double-leg (U-tube) instrument designed to measure the difference between two fluid pressures near to normal atmospheric pressure (14.7 psi). The *barometer* and the *sphygmomanometer* that measures arterial blood pressure are common forms of the manometer.

maser. (microwave amplification by stimulated emission of radiation). A device that converts incident electromagnetic radiation from a wide range of frequencies to one or more discrete frequencies of highly amplified microwave radiation.

mass. The quantity (amount) of matter contained in a substance. Mass is constant regardless of its location in the universe. Mass should not be confused with weight.

mean. Determined by adding all the values or a set of numbers and dividing the sum by the total numbers or values. Usually associated with the term "average."

meiosis. A type of division of the nuclei of cells during which the number of chromosomes is reduced by half.

membranes. In the field of astrophysics, membranes are multidimensional objects that are components of M-theory which is a proposed "master theory" that unites five superstring theories within a single dominant framework to explain the universal forces. M-theory purports to involve eleven space-time dimensions, of which membranes, or branes or p-branes, are a theoretical ingredient that helps explain the concept of strings as the model for the universe.

memes. Units of cultural information that flourish from one individual to another in much the same manner as genes propagate from one organism to another during biological evolution, that is by the process of natural selection. Examples of memes are belief systems, clothing fashions, pottery styles, music, slogans. The concept of memes has spawned its own abstract scientific theory called "memetics."

meson. An elementary particle with strong nuclear interactions, having a baryon number zero. Mesons are unstable and decay to the lowest accessible mass states.

metabolism. A chemical transformation that occurs in organisms when nutrients are ingested, utilized, and finally eliminated (e.g., digestion, absorption, followed by a complicated series of degradations, syntheses, hydrolysis, and oxidations utilizing enzymes, bile acids, and hydrochloric acid). Energy is an important by-product of the metabolizing of food.

meteorite. A small portion of a larger meteor, meteoroid, or a disintegrated chunk of an asteroid that has not completely vaporized as it entered and passed through Earth's atmosphere and that eventually lands on Earth's surface.

mitochondria. In cell biology, mitochondria (singular: mitochondrion) are the membrane-enclosed organelles that are found in most eukaryotic cells. They contain enzymes responsible for the conversion of food into usable energy in the cytoplasm of cells. They have their own DNA (mitochondrial DNA or mtDNA), as well as their own independent genomes.

mole. The SI base unit that measures the amount of substance of a system with a weight in grams numerically equal to the molecular weight of the substance. It is equal to the amount of the substance that contains as many elementary units as there are atoms in 0.012kg of carbon-12. This is known as Avogadro's constant. The mole's use is usually limited to the measurement of subatomic, atomic, and nuclear particles. Symbol: mol.

molecule. The smallest particle of a substance containing more than one atom (e.g., O_2) or a compound that can exist independently. It is usually made up of a group of atoms joined by covalent bonds.

morphology. In biology, the study of the form and structure of living organisms, primarily their external structure.

Mössbauer effect. A physical phenomenon involving the resonant and recoil-free emission and absorption of gamma rays by atoms bound in solid form.

muon. The semistable second generation lepton, with a mass 207 times that of an electron. It has a spin of one-half and a mass of approximately 105 MeV, and a mean lifetime of approximately 2.2×10^{-6} second. Also known as *mu-meson*.

nanotechnology. A field of applied science and technology dealing with the control of matter on the atomic and molecular scale (1 to 100 nanometers), and the fabrication of devices and products within that size. Examples: computer chips; polymers based on molecular structure.

nebula. An immense and diffuse cloudlike mass of gas and interstellar dust particles, visible due to the illumination of nearby stars. Examples are the Horsehead Nebula in Orion and the Trifid Nebula in Sagitarius.

neutrino. An electrically neutral, stable fundamental particle in the lepton family of subatomic particles. It has a spin of one-half and a small or possibly a zero at-rest mass, with a weak interaction with matter. Neutrinos are believed to account for the continuous energy distribution of beta particles and are believed to protect the angular momentum of the beta decay process.

neutron. A fundamental particle of matter with a mass of 1.009 (of a proton) and having no electrical charge. It is a part of the nucleus of all elements except hydrogen.

nucleon. A general term for either the neutron or proton, in particular as a constituent of the nucleus.

nucleosynthesis. The process of creating new atomic nuclei from pre-existing nucleons (protons and neutrons), or the synthesis of chemical elements by nuclear processes. *Primordial nucleosynthesis*, also call nucleogenesis, occurred within a few minutes after the "big bang" when the universe was extremely hot and was responsible for the abundance of lighter elements, such as helium, in our cosmos. *Stellar nucleosynthesis*, the principal form of nucleosynthesis today, takes place in stars by either nuclear fusion or nuclear fission.

nucleotide. The structural unit of nucleic acid found in RNA and DNA.

nucleus. The core of an atom which provides almost all of the atom's mass. It contains protons, neutrons, and quarks held together by gluons (except hydrogen's nucleus which is a single proton) and has a positive charge equal to the number of protons. This charge is balanced by the negative charges of the orbital electrons.

organelle. A distinct subcellular structure, with a specific function and defined shape and size, found in the cytoplasm of the cell (e.g., mitochondria).

oxide. A compound formed when oxygen combines with one other element—a metal or nonmetal (e.g., magnesium oxide).

ozone layer. The layer is found in the upper atmosphere, between 10 and 30 miles in altitude. This thin layer of gases contains a high concentration of ozone gas (O_3) which partially absorbs solar ultraviolet (UV) radiation and prevents it from reaching Earth. It is mostly formed over the equator and drifts toward the North and South Poles. It seems to have a cyclic nature. Also called the *ozonosphere*.

pangenes. In evolutionary theory, they are hypothetical protoplasmic particles inside the nuclei of the cells of living organisms that control heredity. Originally coined by Darwin, it is a term no longer considered to be accurate, nor is it used by credible biologists.

parallax. The apparent change in direction and/or position of an object viewed through an optical instrument (e.g., telescope), which occurs by the shifting position of the observer's line of sight.

particle. A very small piece of a substance that maintains the characteristics of that substance. Also known as fundamental particles found in atoms.

particle accelerator. A machine designed to speed up the movement of electrically charged subatomic particles that are directed at a target. These subatomic particles, also called *elementary particles*, cannot be further divided. They are used in high-energy physics to study the basic nature of matter, as well as the origin of life, nature, and the universe. Particle accelerators are also used to synthesize elements by "smashing" subatomic particles into nuclei to create new, heavy, unstable elements, such as the superactinides. *See also* cyclotron.

parton. In particle physics, a termed originated by Richard Feynman in the late 1960s. It is a theoretical point-like fundamental particle that is a constituent of the proton, neutron, and other baryons. Today these particles are called quarks and gluons. The parton model aids in the interpretation of very high-energy experiments on nucleons as well as short-distance interactions.

Periodic Table of the Chemical Elements. An arrangement of the chemical elements in sequence in the order of increasing atomic numbers. It is arranged in horizontal rows for periods and in vertical columns for groups and illustrates the similarities in properties of the chemical elements.

phage. A parasitic virus in a bacterium that has been isolated from a prokaryote. Also called *bacteriophage*.

phlogiston. The hypothetical substance believed to be the volatile component of combustible material. It was used to explain the principle of fire before oxidation and reduction were known and prior to the discovery of the principle of combustion.

photon. The quantum unit of electromagnetic radiation or light that can be thought of as a particle. Photons are emitted when electrons are excited and move from one energy level (orbit) to another.

photosynthesis. Process by which chlorophyll-containing cells in plants and bacteria convert carbon dioxide and water into carbohydrates, resulting in the simultaneous release of energy and oxygen.

phyla. (plural of **phylum**). A primary taxonomic ranking of organisms into groups of related classes. Phyla are grouped into kingdoms, except in most plants where kingdom is replaced by division.

pi. The transcendental number 3.141592 for the ratio of the circumference of any circle to its diameter, using the symbol π.

pion. A short-lived elementary particle classified as a meson which is primarily responsible for the strong nuclear force. It exists in three forms: neutral, positively charged, and negatively charged. The charged pions decay into muons and neutrinos, and the neutral pion decays into two gamma ray photons. Also called *pi-meson*.

polygon. A simple closed curve in the plane that is bounded by three or more line segments.

positron. The positively charged antiparticle of an electron: e^+ or p^+.

prebiotic. Refers to the period on Earth before the existence of organic life.

precession. Refers to the wobbling or circling of Earth's orbit. It is a complex motion of a rotating body (Earth) subject to a torque acting upon it as a result of gravity.

primordial. The original or first in a sequence, usually referring to the earliest stage of development of an organism or its parts.

prism. A homogeneous, transparent solid, usually with a triangular base and rectangular sides, used to produce or analyze a continuous spectrum of light.

prokaryote. Any organism of the Prokaryote kingdom in which the genetic material is not enclosed within the cell nucleus and possesses a single double-stranded DNA molecule. Only bacteria and cyanobacteria are prokaryotes. All other organisms are eukaryotes.

proton. A positively charged particle found in the nucleus of an atom.

quantum. The basic unit of electromagnetic energy that is not continuous, but occurs in discrete bundles called "quanta." For example, the photon is a small packet (quantum) of light with both particle and wave-like characteristics. A quantum unit for radiation is the frequency v to the product $\hbar v$, where $\hbar$ is Planck's constant. The quantum number is the basic unit used to measure electromagnetic energy. To simplify, it is a very small bit or unit of something.

quark. A hypothetical subnuclear particle having an electric charge one-third to two-thirds that of the electron. Also known as the *fundamental subatomic particle*, which is one of the smallest units of matter.

radical. Also known as "free radical." A group of atoms having one unpaired electron. Also, in mathematics, a given root of a quantity.

radioisotope. The isotopic form of a natural or synthetic element that exhibits radioactivity. The same as a radioactive isotope of an element.

rectifier. A device (diode) that converts alternating current (AC) to direct current (DC).

reduction. The acceptance of one or more electrons by an atom or ion, the removal of oxygen from a compound, or the addition of hydrogen to a compound.

resistors. Two-terminal devices used in electric and electronics circuits that are designed to resist an electric current, thus limiting the flow of the current or causing a drop in voltage.

retrovirus. An animal virus containing RNA in which the genome replicates through reverse transcription and which has two proteinaceous structures, enabling it to combine with the host's DNA. Retroviruses contain oncogenes, which are cancer-causing genes that become activated once the virus enters the host's cell and begins to reproduce itself.

RNA. Abbreviation for *ribonucleic acid*. The linear, single-stranded polymer of ribonucleotides, each of which contains sugar (ribose) and one of four nitrogen bases (adenine, guanine, cytosine, uracil). It is present in all living cells (prokaryotic and eukaryotic) and carries the genetic code, which is transcribed from the DNA to the ribosomes within the cell where this genetic information is reproduced.

semiconductor. Usually a "metalloid" (e.g., silicon) or a compound (e.g., gallium arsenide), which has conductive properties greater than those of an insulator but less than those of a conductor (metal). It is possible to adjust their level of conductivity by changing the temperature or adding impurities.

sidereal period. The actual period (length of time) of revolution of a planet in its orbit around the sun using the stars as reference points.

singularity. Often referred to as a space-time singularity, it is a region of space-time where one or more components of curved spaces become infinite. Also defined as the location at which the fabric of space-time experiences a "devastating rupture." Examples of space-time singularities: the big bang, black holes.

solar system. Consists of the sun and the other celestial objects that are bound to it by gravitational forces, including the eight planets and three dwarf planets (Ceres, Eris, and Pluto) that orbit the sun along with their satellites (moons), asteroids, comets, meteors, as well as the remnants from the formation of the solar system that are located in the region called the Kuiper belt.

solenoid. An electromagnetic coil of insulated wire that produces a magnetic field within the coil. Most often it is shaped like a spool or hollow cylinder with a movable iron core that is pulled into the coil when electric current is sent through the wire. It then is able to move other instruments, for example, relay switches, circuit breakers, automobile ignitions.

soma. The entire physical body of an organism, with the exception of its germ cells and tract.

species. The lowest ranking in the classification of organisms. It is the distinguishable group with a common ancestry, able to reproduce fertile offspring, and that are geographically distinct. (Related species are grouped into a genus.)

spectrophotometry. The quantitative analysis of radiant energy, specifically visible, ultraviolet, and infrared light, as well as X-rays. With a spectrophotometer, an instrument designed to measure light intensity, it is possible to measure light intensity as a function of color, in other words, the wavelength of light.

spectroscopy. The analysis of chemical elements that separates the unique light waves either given off or absorbed by the elements when heated.

Standard Model. In particle physics, a collection of established experimental knowledge and theories that summarize the field. It includes the three generations of quarks and leptons, the electroweak theory of weak and electromagnetic forces, and quantum chromodynamic theory of strong forces.

steroid. A class of lipid proteins, such as sterols, bile acids, sex hormones, or adrenocortical hormones, that are derived from cyclopentanoperhydrophenanthrene. A shorter term for *anabolic steroid.*

stoichiometry. The calculation of measurable numerical relationships of chemical elements and chemical compounds as reactants and products in chemical reactions.

subatomic particle. A component of an atom whose reactions are characteristic of the atom, for example, electrons, protons, and neutrons.

superconductivity. A property of a metal, alloy, or compound that at temperatures near absolute zero loses both electrical resistance and magnetic permeability (is strongly repelled by magnets), thereby having infinite electrical conductivity.

supernova. A great explosion of a large star that collapses because of its gravitational force, sending great bursts of electromagnetic radiation (light) into space.

superstrings. In physics, a component of superstring theory incorporating supersymmetry that is an attempt to explain the fundamental forces of nature and all the particles into one theory of general relativity. Superstrings are one-dimensional, closed curves or loops of vibrating energy with zero thickness and length that is measured as the Planck length, namely, 10^{-35} m.

syllogism. In broad terms, it is a form of a "logical argument" in which the conclusion is inferred from a major and a minor premise. It is the basis of *deductive reasoning*, that is, reasoning from the general to the specific, and is sometime referred to as specious reasoning.

symbiosis. The interrelationship between two different organisms or two different species in which one but not always both benefit. For instance, *parasitism* is a form of symbiosis.

systolic. Refers to *systole* which is the rhythmic contraction of the heart, particularly the ventricles, by which blood is driven through the aorta and pulmonary artery after each dilation or diastole.

tetanus. An infectious disease of both humans and animals caused by the *Clostridium tetani* bacteria. Infection can occur after a deep wound is contaminated by dirt. Symptoms include violent and involuntary muscle spasms and contractions, including those of the jaw. Hence, the common term for tetanus—*lockjaw*. A vaccine for tetanus is routinely administered whenever an injury involves an open wound that has been exposed to dirt or debris.

thermionic emission. The emission of electrons or ions, usually into a vacuum, from a heated object, such as a cathode of a thermionic tube.

thermodynamics. The study of energy and laws governing transfer of energy from one form to another, particularly relating to behavior of systems where temperature is a factor (i.e., direction of the flow of heat and availability of energy to perform work).

thermonuclear. Release of heat energy when the nuclei of atoms split (fission, atom bomb, or nuclear power plant) or when nuclei combine (fusion, hydrogen bomb).

tincture. An alcoholic extract (e.g., vegetable or herb) or a solution of a nonvolatile substance (e.g., iodine). They are more dilute, usually only 10%, than fluid extracts and less volatile than spirits.

transistor. A device that overcomes the resistance when a current of electricity passes through it, used widely in the electronics industry.

ultraviolet (UV). The radiation wavelength in the electromagnetic spectrum from 100 to 3,900 angstroms (Å), between the X-ray region and visible violet light.

universe. All the space, matter, and energy that exists, including that which existed in the past and is postulated to exist in the future.

valence. The whole number that represents the combing power of one element with another element. Valence electrons are usually, but not always, the electrons in the outermost shell.

vector. A quantity specified by magnitude and direction whose components convert from one coordinate system to another in the same manner as the components of a displacement. Vector quantities may be added and subtracted.

velocity. The time rate at which an object is displaced. Velocity is a vector quantity whose quantity is measured in units of distance over a period of time.

weight. The measure of the mass or heaviness of an object. It is determined by the gravitational force exerted on an object.

zygote. A fertilized egg that develops into an embryo. It is the product of the union of two gametes.

APPENDIX A

Alphabetical Listing of Entries by Scientific Discipline

ANTHROPOLOGY

Johanson; Leakey

ASTRONOMY

Adhemar; Airy; Al-Battani; Ambartsumian; Ångstrom [also *Physics*]
Baade; Bahcall; Bessel [also *Mathematics*]; Bode; Bok; Bradley; Brahe; Burbidge (aka B2FH)
Cassini; Chandrasekhar; Chang (Heng) [also *Mathematics*]; Copernicus
Douglass; Drake
Eddington, Eratosthenes; Eudoxus
Fairbank; Friedmann
Geller; Gold; Guth
Hale; Halley; Hawking; Herschels; Hertzsprung; Hewish; Hoyle; Hubble; Huggins
I-Hsing [also *Mathematics*]
Janssen; Jeans; Jeffreys (Harold)
Kapteyn; Kepler; Kimura (Hisashi); Kirkwood; Kuiper
Lambert [also *Mathematics, Physics*]; Leavitt; Lemaître; Lockyer; Lovell; Lowell
Maunder; Misner
Nicholas
Olbers; Oort
Penzias; Pogson; Poseidonius; Ptolemy
Roche; Rubin; Russell; Ryle
Sagan; Saha; Sandage; Schiaparelli; Schmidt; Schwarzschild; Shapley; Slipher; Smoot; Spencer-Jones; Struve
Taylor
Whipple; Wolf
Zwicky

BIOCHEMISTRY

Elion
Fox
Kendall; Khorana
Merrifield; Mullis [also *Biology*]
Porter
Theorell; Todd
Wrinch

BIOLOGY

Baer; Bakker; Baltimore; Behring; Bonnet; Buffon
Candolle; Chambers; Chang (Min Chueh); Chargaff; Clarke; Cohn; Crick–Watson; Cuvier
Dale; Darlington; Darwin; Dawkins; De Beer; Delbruck/Luria; De Vries; d'Herelle; Dobzhansky; Dulbecco
Einthoven; Eldredge; Elton; Erasistratus
Fabricius; Fallopius; Fleming (Alexander); Florey; Fracastoro [also *Medicine*]
Galen; Gallo; Galton; Garrod [also *Medicine*]; Gilbert (Walter); Goldstein [also *Medicine*]; Gould
Haeckel; Haldane; Harvey
Ingenhousz; Ingram; Isaacs
Jacob-Monod; Jeffreys (Alec); Jenner; Jerne
Kimura (Motoo); Koch
Lamarck; Landsteiner; Lederberg; Leeuwenhoek; Leishman; Levene; Levi-Montalcini; Linnaeus; Lister; Lysenko
Malpighi; Malthus; Margulis; Maynard-Smith; McClintock; Mendel; Meselson–Stahl; Miescher; Muller; Mullis [also *Biochemistry*]
Neher [also *Physics*]; Nicolle
Ochoa; Oken; Oparin
Pardee; Pasteur; Perutz; Pfeiffer
Ramón y Cajal; Raup; Ray; Redi; Reed; Reichstein [also *Chemistry*]; Robbins; Roberts
Sabin; Sachs; Sarich; Schleiden; Schwann; Sharp; Spallanzani; Strasburger; Swammerdam
Tatum; Temin; Theophrastus; Tonegawa
Vesalius; Virchow
Waddington; Waldeyer-Hartz; Wallace; Watson–Crick; Weismann; Wilson (Allan); Wilson (Edward); Wright (Sewall); Wynne-Edwards
Yanofsky
Zuckerandl

CHEMISTRY

Abegg; Adams; Arrhenius; Aston [also *Physics*]; Avogadro
Babo; Baekeland; Baeyer; Berzelius; Black; Boyle; Bunsen
Calvin; Cannizzaro; Caspersson; Cavendish; Charles; Chevreul; Claude; Corey; Cori; Couper; Crutzen; Curie; Curl
Daguerre; Dalton; Daniell; Davy; Debye-Hückel; Democritus; Dewar [also *Physics*]; Djerassi; Döbereiner; Domagk; Draper, Dumas

Ehrlich; Eigen; Elion; Ernst; Eyring
Fajans; Fischer; Fleischmann; Flory; Frankland
Gay-Lussac; Gerhardt; Giauque [also *Physics*]; Graham
Haber; Hahn; Harkins; Haworth; Helmont; Higgins; Hodgkin; Hoffman; Hückel
Ideal Gas Law; Ingold; Ipatieff
Kekule; Kipping; Krebs; Kroto
Langmuir; Laurent; Lavoisier; Le Bel; Le Chatelier; Lewis; Liebig
Martin; Mendeleev; Meyer; Miller; Mitscherlich; Mulliken
Natta; Nernst; Newlands; Noddack; Norrish; Northrop
Odling; Ostwald
Paracelsus; Parkes; Pauling; Ponnamperuma; Priestley; Prigogine; Proust
Ramsay; Reichstein [also *Biology*]; Revelle; Rowland
Sanger; Scheele; Seaborg; Sidgwick; Soddy; Sorensen; Spedding; Stahl
Tiselius; Turner
Urey
Van't Hoff
Wallach; Werner (Alfred); Wilkinson; Williamson; Wohler; Woodward; Wurtz
Ziegler

COMPUTER SCIENCE
Amdahl; Metcalfe; Minsky [also *Mathematics*]; Moore [also *Mathematics*]

GEOLOGY
Agassiz; Agricola; Airy [also *Astronomy*]
Barringer; Beaumont
Charpentier
Dana
Ekman; Ewing
Haüy; Hess (Harry)
Lyell
Mohorovicic
Richter
Shepard; Steno; Suess
Wegener; Werner (Abraham)

MATHEMATICS
Abel; Archimedes
Babbage; Balmer [also *Physics*]; Banach; Bernoulli (Daniel) [also *Physics*]; Bernoulli (Jakob); Bessell [also *Astronomy*]; Boole
Cantor; Cardano; Chang (Heng) [also *Astronomy*]; Chapman-Enskog [also *Physics*]; Conway
D'Alembert [also *Physics*]
Euclid; Euler
Fermat; Fibonacci
Gauss; Gibbs [also *Physics*]; Godel
Hadamard; Hamilton; Hardy
I-Hsing [also *Astronomy*]

Lagrange; Lambert [also *Astronomy*, *Physics*]; Liebniz; Lindemann; Lorenz
Minsky [also *Computer Science*]; Moore [also *Computer Science*}
Nash; Noether
Peano; Pearson; Pythagoras
Regiomontanus; Reichenbach [also *Philosophy*]; Riemann
Snell [also *Physics*]
Tartaglia; Turing
Ulam
Von Neumann
Whitehead [also *Physics*]

MEDICINE
Banting; Bell
Fracastoro
Garrod; Goldstein
Mesmer; Montagnier

METEOROLOGY
Bergeron; Bjerknes [also *Physics*]
Charney [also *Physics*]
Hadley
Schneider

MICROBIOLOGY
Arber; Enders; Nathans

PHILOSOPHY
Anaximander
Bacon
Descartes
Reichenbach [also *Mathematics*]
Thales

PHYSICS
Abbe; Alvarez; Ampère; Anderson (Carl); Anderson (Philip); Ångström [also *Astronomy*]; Arago; Aristotle; Aston [also *Chemistry*]; Atomism Theories; Auger
Babinet; Balmer [also *Mathematics*]; Bardeen; Becquerel; Beer; Bernoulli (Daniel) [also *Mathematics*]; Bethe; Biot-Savart; Birkeland; Bjerknes [also *Meteorology*]; Bohm; Bohr; Boltzmann; Born-Haber
Cagniard de La Tour; Cailletet; Carnot; Casimir; Celsius; Chadwick; Chapman-Enskog [also *Mathematics*]; Charney [also *Meteorology*]; Charpak; Chu; Clausius; Cockroft-Walton; Compton; Coriolis; Coulomb; Crookes
D'Alembert [also *Mathematics*]; Davisson; De Broglie; Dehmelt; Dewar [also *Chemistry*]; Dicke; Diesel; Dirac; Doppler; Dyson
Edison; Einstein; Eötvös; Esaki; Everett

Fahrenheit; Faraday; Fermi; Fessenden; Feynman; Fick [also *Physiology*]; Fitzgerald; Fizeau; Fleming (John); Flerov; Foucault; Fourier; Fowler; Franck; Franklin (Benjamin); Franklin (Rosalind); Fraunhofer; Fresnel; Friedman; Frisch

Gabor; Galileo; Galvani; Gamow; Gassendi; Geiger–Nutter; Gell-Mann; Giauque [also *Chemistry*]; Gibbs [also *Mathematics*]; Gilbert (William); Glaser; Glashow

Hall; Heisenberg; Helmholtz; Henry; Hertz; Hess (Victor); Higgs; Hooke; Huygens

Jansky; Joliot-Curie; Josephson; Joule

Kamerlingh-Onnes; Kapitsa; Karle; Kelvin; Kerr; Kerst; Kirchhoff; Klitzing; Kohlrausch; Kusch

Lamb; Lambert [also *Astronomy*, *Mathematics*]; Landau; Landauer; Langevin; Laplace; Larmor; Lawrence; Lederman; Lee; Lenard; Lenz; Lorentz

Mach; Maiman; Malus; Mansfield; Marconi; Matthias; Maupertuis; Maxwell; McMillan; Meissner; Meitner; Michelson; Millikan; Minkowski; Moseley

Nambu; Néel; Neher [also *Biology*]; Newcomb; Newton; Noyce

Oersted; Ohm; Oliphant; Oppenheimer

Pascal; Pauli; Peierls; Penrose; Perl; Perrin; Planck; Poynting; Prévost; Purcell

Quantum Theories

Rabi; Raman; Ramsey; Raoult; Rayleigh; Reines; Ricciolo; Richardson; Röentgen; Romer; Rossi; Rubbia; Rumford; Rutherford; Rydberg

Sakharov; Salam; Schrödinger; Schwinger; Seebeck; Segre; Shockley; Siemens; Simon; Snell [also *Mathematics*]; Stark; Stefan; Steinberger; Stern; Stokes; Stoney; Szilard

Tamm; Teller; Tesla; Thomson; Ting; Tomonaga; Torricelli; Townes; Townsend; Tyndall

Uhlenbeck

Van Allen; Van de Graaf; Van der Meer; Van der Waals; Van Vleck; Volta; Von Laue

Walton; Watson (William); Watson-Watt; Weber; Weinberg; Weizsäcker; Wheeler; Whitehead [also *Mathematics*]; Wien; Wigner; Wilson (Charles); Witten; Wolfram; Wu

Yalow; Yang; Young; Yukawa

Zeeman; Zeno; Zinn

PHYSIOLOGY

Fick [also *Physics*]; Langley; Pavlov

APPENDIX B

Nobel Laureates in Chemistry (1901–2007)

Nobel laureates are listed consecutively by year starting with 1901 and ending with 2007. The country indicates where the chemist did major work. If the chemist's country of birth is different than where major work was, or is, done, this is indicated after the "b." In many years, several chemists are recognized. When this occurs, it may be for work in similar areas of chemistry for working collaboratively, or independently. When the prize has been shared for work in an entirely different area, the name, country, and work are shown as a separate entry.

Year	Recipient(s)	Country	Work
1901	Jacobus van't Hoff	Germany, b. Netherlands	laws of chemical dynamics and osmotic osmotic pressure in solutions
1902	Herman Emil Fischer	Germany	sugar and purine syntheses
1903	Svante August Arrhenius	Sweden	electrolytic dissociation theory
1904	William Ramsay	United Kingdom	discovery of noble gases
1905	Adolf von Baeyer	Germany	organic dyes and hydroaromatic compounds
1906	Henri Moissan	France	isolation of fluorine and electric furnace
1907	Eduard Buchner	Germany	fermentation in absence of cells and biochemistry
1908	Ernest Rutherford	United Kingdom, b. New Zealand	radioactive decay
1909	Wilhelm Ostwald	Germany, b. Russia	chemical equilibrium, kinetics, and catalysis

(Continued)

Year	Recipient(s)	Country	Work
1910	Otto Wallach	Germany	pioneering work with alicyclic compounds
1911	Marie Curie	France, b. Poland	discovery of radium and polonium
1912	Victor Grignard	France	discovery of Grignard's reagent
	Paul Sabatier	France	hydrogenation with metal catalysts
1913	Alfred Werner	Switzerland, b. Germany	bonding of inorganic compounds
1914	Theodore Richards	United States	determination of atomic weights
1915	Richard Willstätter	Germany	studies of plant pigments, especially chlorophyll
1916*			
1917*			
1918	Fritz Haber	Germany	synthesis of ammonia
1919*			
1920	Walter H. Nernst	Germany	thermochemistry
1921	Frederick Soddy	United Kingdom	radioactive substances and isotopes
1922	Francis W. Aston	United Kingdom	mass spectrography and discovery of isotopes
1923	Fritz Pregl	Austria	organic microanalysis
1924*			
1925	Richard A. Zsigmondy	Germany, b. Austria	colloid chemistry
1926	Theodore Svedberg	Sweden	disperse systems
1927	Heinrich Otto Wieland	Germany	bile acids
1928	Adolf Windaus	Germany	sterols relationship with vitamins
1929	Arthur Harden	United Kingdom	fermentation of sugar and sugar enzymes
	Hans von Euler-Chelpin	Sweden, b. Germany	
1930	Hans Fischer	Germany	synthesis of haemin
1931	Carl Bosch	Germany	high-pressure chemical processing
	Friedrich Bergius	Germany	
1932	Irving Langmuir	United States	surface chemistry
1933‡			
1934	Harold Urey	United States	discovery of heavy hydrogen
1935	Frédéric Joliot	France	synthesis of new radioactive elements
	Irène Joliot-Curie	France	
1936	Peter Debye	Germany, b. Netherlands	dipole moments and X-ray diffraction
1937	Norman Haworth	United Kingdom	carbohydrates and vitamin C
	Paul Karrer	Switzerland	vitamins A and B12

Year	Recipient(s)	Country	Work
1938	Richard Kuhn	Germany, b. Austria	carotenoids and vitamins
1939	Adolf F. J. Butenandt	Germany	sex hormones
	Leopold Ruzicka	Switzerland, b. Hungary	polymethylenes and terpenes
1940‡			
1941‡			
1942‡			
1943	George DeHevesy	Sweden, b. Hungary	isotope tracers
1944	Otto Hahn	Germany	fission of heavy nuclei
1945	Artturi I. Virtanen	Finland	agricultural and food chemistry and preservation of fodder
1946	James Sumner	United States	crystallization of enzymes
	John H. Northrop	United States	preparation of proteins and enzymes in pure form
	Wendell Stanley	United States	
1947	Robert Robinson	United Kingdom	alkaloids
1948	Arne W. K. Tiselius	Sweden	electrophoresis and serum proteins
1949	William F. Giauque	United States	low temperature thermodynamics
1950	Otto Diels	Germany	diene synthesis
	Kurt Alder	Germany	
1951	Edwin McMillan	United States	chemistry of transuranium elements
	Glenn Seaborg	United States	
1952	Archer J. P. Martin	United Kingdom	invention of partition chromatography
	Richard L. M. Synge	United Kingdom	
1953	Hermann Staudinger	Germany	macromolecular chemistry
1954	Linus Pauling	United States	chemical bonding and molecular structure of proteins
1955	Vincent Du Vigneaud	United States	sulfur compounds of biological importance; synthesis of polypeptide hormone
1956	Cyril Hinshelwood	United Kingdom	mechanisms of chemical reaction
	Nikolay Semenov	USSR	
1957	Alexander Todd	United Kingdom	nucleotides and their co-enzymes
1958	Frederick Sanger	United Kingdom	protein structure; insulin
1959	Jaroslav Heyrovsky	Czechoslovakia	polarographic methods of analysis
1960	Willard Libby	United States	carbon-14 dating
1961	Melvin Calvin	United States	CO_2 assimilation in plants
1962	Max Perutz	United Kingdom, b. Austria	structure of globular proteins
	John Kendrew	United Kingdom	

(Continued)

Year	Recipient(s)	Country	Work
1963	Giulio Natta	Italy	high polymers
	Karl Ziegler	Germany	
1964	Dorothy Crowfoot Hodgkin	United Kingdom	X-ray techniques of the structures of biochemical substances
1965	Robert Woodward	United States	organic synthesis
1966	Robert Mulliken	United States	chemical bonds and electronic structure of molecules
1967	Manfred Eigen	Germany	study of very fast chemical reactions
	Ronald Norrish	United Kingdom	
	George Porter	United Kingdom	
1968	Lars Onsager	United States, b. Norway	thermodynamic of irreversible processes
1969	Derek Barton	United Kingdom	conformation
	Odd Hassel	Norway	
1970	Luis Leloir	Argentina	sugar nucleotides and carbohydrate biosynthesis
1971	Gerhard Herzberg	Canada, b. Germany	structure and geometry of free radicals
1972	Christian Anfinsen	United States	ribonuclease, amino acid sequencing and biological activity
	Stanford Moore	United States	chemical structure and catalytic activity of ribonuclease
	William Stein	United States	
1973	Ernst Fischer	Germany	organometallic sandwich compounds
	Geoffrey Wilkinson	United Kingdom	
1974	Paul Flory	United States	macromolecules
1975	John Cornforth	United Kingdom	stereochemistry of enzyme-catalyzed reactions;
	Vladmir Prelog	Switzerland, b. Bosnia	stereochemistry of organic molecules
1976	William Lipscomb	United States	structure of borane and bonding
1977	Ilya Prigogine	Belgium, b. Russia	theory of dissipative structures
1978	Peter Mitchell	United Kingdom	chemiosmotic theory
1979	Herbert Brown	United States, b. United Kingdom	organic synthesis of boron and phosphorus compound
	George Wittig	Germany	
1980	Paul Berg	United States	recombinant DNA
	Walter Gilbert	United States	nucleic acid base sequences
	Frederick Sanger	United Kingdom	

Year	Recipient(s)	Country	Work
1981	Kenichi Fukui	Japan	chemical reactions and orbital theory
	Roald Hoffman	United States, b. Poland	
1982	Aaron Klug	United Kingdom	crystallographic electron microscopy applied to nucleic acids and proteins
1983	Henry Taube	United States, b. Canada	electron transfer in metal complexes
1984	Bruce Merrifield	United States	chemical synthesis
1985	Herbert Hauptman	United States	crystal structures
	Jerome Karle	United States	
1986	Dudley Herschbach	United States	chemical elementary processes
	Yuan Lee	United States, b. Taiwan	
	John Polanyi	Canada	
1987	Donald Cram	United States	development of molecules with
	Jean-Marie Lehn	France	highly selective structure
	Charles Pedersen	United States, b. Korea (Norwegian)	specific interactions
1988	Johann Deisenhofer	Germany and United States, b. Germany	photosynthesis
	Robert Huber	Germany	
	Hartmut Michel	Germany	
1989	Sidney Altman	United States, b. Canada	catalytic properties of RNA
	Thomas R. Cech	United States	
1990	Elias J. Corey	United States	organic synthesis
1991	Richard Ernst	Switzerland	nuclear resonance spectroscopy
1992	Rudolph Marcus	United States, b. Canada	electron transfer in chemical systems
1993	Kary Mullis	United States	invention of PCR method;
	Michael Smith	Canada, b. United Kingdom	mutagenesis and protein studies
1994	George Olah	United States, b. Hungary	carbocation chemistry
1995	Paul Crutzen	Germany, b. Netherlands	atmospheric chemistry
	Mario Molina	United States, b. Mexico	stratospheric ozone depletion
	F. Sherwood Rowland	United States	
1996	Robert Curl Jr.	United States	discovery of fullerenes
	Harold Kroto	United Kingdom	
	Richard Smalley	United States	

(Continued)

Year	Recipient(s)	Country	Work
1997	Paul Boyer	United States	enzyme mechanism of ATP
	John Walker	United Kingdom	discovery of ion transport enzyme NA+, K+-ATPase
	Jens Skou	Denmark	
1998	Walter Kohn;	United States	density function theory;
	John Pople	United Kingdom	computational methods in quantum chemistry
1999	Ahmed Zewail	United States, b. Egypt	transition states using femto spectroscopy
2000	Alan J. Heeger	United States	discovery of conductive polymers
	Alan MacDiarmid	United States	
	Hideki Shirakawa	Japan	
2001	William Knowles	United States	chirally catalyzed hydrogenation reactions
	Ryoji Noyori	Japan	
	K. Barry Sharpless	United States	
2002	John B. Fenn	United States	identification of biological macromolecules
	Koichi Tanaka	Japan	
	Kurt Wüthrich	Switzerland	NMR analysis of biological macromolecules
2003	Peter Agre	United States	discovery of water channels;
	Roderick MacKinnon	United States	structural and mechanistic studies of ion channels
2004	Aaron Ciechanover	Israel	discovery of ubiquitin-mediated protein degradation
	Avram Hershko	Israel, b. Hungary	
	Irwin Rose	United States	
2005	Yves Chauvin	France	development of the metathesis method in organic synthesis
	Robert H. Grubbs	United States	
	Richard R. Schrock	United States	
2006	Roger D. Kornberg	United States	molecular bases of eukaryotic transcription
2007	Gerhard Ertl	Germany	chemical processes on solid surfaces

Source: Nobelprize.org.

* No prize awarded. Prize money allocated to the Special Fund of the Nobel Prize section for chemistry.

‡ No prize awarded. Prize money was allocated as follows: 1/3 to the Nobel Prize main fund, and 2/3 to the Special Fund of the Nobel Prize section for chemistry.

APPENDIX C

Nobel Laureates in Physics (1901–2007)

Nobel laureates are listed consecutively by year starting with 1901 and ending with 2007. The first country shown indicates where the physicist did major work. If the physicist's country of birth is different than where the major work was, or is, done, this is indicated after the "b." In some years, several physicists shared the Nobel Prize for work in similar areas of physics, either working collaboratively, or independently, and their names are listed as such. When the prize has been shared for work in an entirely different area, the name, country, and work are shown as a separate entry.

Year	Recipient(s)	Country	Work
1901	Wilhelm Röentgen	Germany	discovery of X-rays
1902	Hendrik A. Lorentz	Netherlands	effect of magnetism on radiation
	Pieter Zeeman	Netherlands	
1903	Henri Becquerel	France	spontaneous radioactivity;
	Marie Curie	France, b. Poland	joint research on Becquerel's discovery of radiation phenomena
	Pierre Curie	France	
1904	John W. Strutt (aka Lord Rayleigh)	United Kingdom	discovery of argon; density of gases
1905	Philipp von Lenard	Germany, b. Austria-Hungary	cathode rays
1906	Sir J. J. Thomson	United Kingdom	electrical conductivity of gases
1907	Albert A. Michelson	United States, b. Germany	spectroscopic metrological investigations with optical precision instruments

(Continued)

Year	Recipient(s)	Country	Work
1908	Gabriel Lippmann	France, b. Luxembourg	photographic reproduction of color
1909	Karl F. Braun	Germany	wireless telegraphy
	Guglielmo Marconi	United Kingdom, b. Italy	
1910	Johannes D. Van der Waals	Netherlands	equation of state for gases and fluids
1911	Wilhelm Wien	Germany	laws on radiation of heat
1912	Nils Gustaf Dalén	Sweden	automatic regulators for gas
1913	Heike Kamerlingh-Onnes	Netherlands	matter at low temperature
1914	Max von Laue	Germany	X-ray diffraction with crystals
1915	Lawrence Bragg	United Kingdom, b. Australia	crystal structure using X-rays
	William Bragg	United Kingdom	
1916*			
1917	Charles G. Barkla	United Kingdom	characteristic Röentgen radiation of elements
1918	Max Planck	Germany	energy quanta
1919	Johannes Stark	Germany	Doppler effect and splitting of spectral lines in electric field
1920	Charles Guillaume	Switzerland	anomalies in nickel and steel alloys
1921	Albert Einstein	Germany and Switzerland, b. Germany	photoelectric effect
1922	Niels Bohr	Denmark	atomic structure and radiation
1923	Robert Millikan	United State	elementary electric charge
1924	Karl M. G. Siegbahn	Sweden	X-ray spectroscopy
1925	James Franck	Germany	impact of electron on atom
	Gustav Hertz	Germany	
1926	Jean Perrin	France	discontinuous structure of matter; sedimentation equilibria
1927	Arthur H. Compton;	United States	Compton effect;
	Charles T. R. Wilson	United Kingdom	invention of cloud chamber
1928	Owen Richardson	United Kingdom	Richardson's law, electron emission of hot metals
1929	Louis de Broglie	France	wave nature of electrons
1930	C. V. Raman	India	Raman effect, light diffusion
1931*			
1932	Werner Heisenberg	Germany	quantum mechanics
1933	Paul Dirac	United Kingdom	discovery of new productive forms of atomic theory
	Erwin Schrödinger	Germany, b. Austria	

Year	Recipient(s)	Country	Work
1934‡			
1935	James Chadwick	United Kingdom	discovery of neutron
1936	Carl D. Anderson	United States	discovery of positron;
	Victor F. Hess	Austria	discovery of cosmic rays
1937	Clinton Davisson	United States	crystal diffraction of electrons
	George Thomson	United Kingdom	
1938	Enrico Fermi	Italy	neutron irradiation and discovery of new elements
1939	E. O. Lawrence	United States	invention of cyclotron
1940‡			
1941‡			
1942‡			
1943	Otto Stern	United States, b. Germany	magnetic moment of the proton
1944	Isidor Rabi	United States, b. Austria-Hungary	magnetic resonance of atomic nuclei
1945	Wolfgang Pauli	United States and Switzerland, b. Austria	exclusion principle of electrons
1946	Percy Bridgman	United States	high-pressure physics
1947	Edward Appleton	United Kingdom	upper-atmosphere physics
1948	Patrick Blackett	United Kingdom	nuclear and cosmic physics with cloud chamber
1949	Hideki Yukawa	United States and Japan, b. Japan	prediction of mesons
1950	Cecil F. Powell	United Kingdom	photographic method for mesons
1951	John D. Cockcroft	United Kingdom	transmutation of atomic nuclei
	Ernest T. S. Walton	Ireland	
1952	Felix Bloch	United States, b. Switzerland	nuclear magnetic resonance methods
	Edward Purcell	United States	
1953	Frits Zernike	Netherlands	phase-contrast microscopy
1954	Max Born	United Kingdom, b. Germany	statistical interpretation of wave function;
	Walther Bothe	Germany	coincidence method
1955	Polykarp Kusch	United States, b. Germany	magnetic moment of the electron;
	Willis Lamb Jr.	United States	structure of hydrogen spectrum
1956	John Bardeen	United States	semiconductors and discovery of transistor effect

(Continued)

Year	Recipient(s)	Country	Work
	Walter Brattain	United States	semiconductors and discovery of transistor effect
	William Shockley	United States	
1957	Tsung-Dao Lee	United States, b. China	parity laws in their application to elementary particles
	Chen Ning Yang	United States, b. China	
1958	Pavel Cherenkov	USSR	discovery and interpretation of Cherenkov effect
	Ilya Frank	USSR	
	Igor Tamm	USSR	
1959	Owen Chamberlain	United States	discovery of antiproton
	Emilio Segrè	United States, b. Italy	
1960	Donald Glaser	United States	invention of bubble chamber
1961	Robert Hofstadter	United States	structure of nucleus;
	Rudolf Mössbauer	United States, b. Germany	absorbance and emission of photons
1962	Lev Landau	USSR	condensed matter and liquid helium
1963	J. Hans Jensen	Germany	nuclear shell structure;
	Maria Goeppert-Mayer	United States, b. Germany	
	Eugene Wigner	United States, b. Hungary	fundamental symmetry principles
1964	Nikolay Basov	USSR	maser-laser principles
	A M. Prokhorov	USSR	
	Charles Townes	United States	
1965	Richard Feynman	United States	quantum electrodynamics
	Julian Schwinger	United States	
	Sin-Itiro Tomonaga	Japan	
1966	Alfred Kastler	France	Hertzian resonance in atoms
1967	Hans Bethe	United States, b. Germany	energy production in stars
1968	Luis W. Alvarez	United States	elementary particles and resonance states
1969	Murray Gell-Mann	United States	quark model and elementary particles
1970	Hannes Alfvén	Sweden	magneto hydrodynamics;
	Louis-Eugene Néel	France	ferrimagnetism and anti-ferromagnetism
1971	Dennis Gabor	United Kingdom, b. Hungary	development of holography

Year	Recipient(s)	Country	Work
1972	John Bardeen	United States	theory of superconductivity, known as the BCS Theory
	Leon N. Cooper	United States	
	John Schrieffer	United States	
1973	Leo Esaki	United States, b. Japan	tunneling in semiconductors
	Ivar Giaever	United States, b. Norway	and superconductors, respectively;
	Brian Josephson	United Kingdom	supercurrents/Josephson effects
1974	Antony Hewish	United Kingdom	radioastrophysics and pulsars
	Sir Martin Ryle	United Kingdom	
1975	Aage N. Bohr	Denmark	atomic nucleus structure
	Ben Mottelson	Denmark, b. United States	
	James Rainwater	United States	
1976	Burton Richter	United States	discovery of J/psi particle
	Samuel C. Ting	United States	
1977	Philip Anderson	United States	electronic structure of magnetic disordered systems
	Sir Nevill F. Mott	United Kingdom	
	John Van Vleck	United States	
1978	Pyotr Kapitsa	USSR	helium liquefaction;
	Arno Penzias	United States, b. Germany	cosmic microwave background radiation
	Robert W. Wilson	United States	
1979	Sheldon Glashow	United States	unification of electromagnetic and weak interaction
	Abdus Salam	Pakistan	
	Steven Weinberg	United States	
1980	James Cronin	United States	violation of symmetry principles in the decay of neutral k-mesons
	Val Fitch	United States	
1981	Nicolaus Bloembergen	United States, b. Netherlands	laser spectroscopy;
	Arthur Schawlow	United States	
	Kai Siegbahn	Sweden	electron spectroscopy
1982	Kenneth G. Wilson	United States	phase transitions
1983	Subrahmanyan Chandrasekhar	United States, b. India;	stellar evolution;
	William A. Fowler	United States	element formation in universe
1984	Simon van der Meer	Switzerland, b. Netherlands	discovery of W and Z particles
	Carlo Rubbia	Switzerland, b. Italy	
1985	Klaus von Klitzing	Germany	quantized Hall effect

(Continued)

Year	Recipient(s)	Country	Work
1986	Gerd Binnig	Switzerland, b. Germany	scanning tunnel microscopy;
	Heinrich Rohrer	Switzerland	
	Ernst Ruska	Germany	electron microscopy
1987	J. Georg Bednorz	Switzerland	superconductivity in ceramics
	K. Alexander Müller	Switzerland	
1988	Leon Lederman	United States	discovery of muon neutrino
	Melvin Schwartz	United States	
	Jack Steinberger	United States and Switzerland, b. Germany	
1989	Hans Dehmelt	United States, b. Germany	ion trap technique
	Wolfgang Paul	Germany	
	Norman Ramsey	United States	atomic clocks
1990	Jerome Friedman	United States	deep inelastic scattering of electrons and quark discovery
	Henry Kendall	United States	
	Richard E. Taylor	Canada	
1991	Pierre-Gilles de Gennes	France	order transitions in liquid crystals
1992	Georges Charpak	France, b. Poland	multiwire proportional chamber detector
1993	Russell Hulse	United States	discovery of binary pulsar
	Joseph Taylor Jr.	United States	
1994	Bertram Brockhouse	Canada	neutron spectroscopy
	Clifford Shull	United States	neutron diffraction technique
1995	Martin Perl	United States	discovery of tau lepton;
	Frederick Reines	United States	detection of the neutrino
1996	David Lee	United States	superfluidity in heavy helium
	Douglas Osheroff	United States	
	Robert Richardson	United States	
1997	Steven Chu	United States	laser cooling and trapping of atoms
	Claude Cohen-Tannoudji	France, b. Algeria	
	William Phillips	United States	
1998	Robert Laughlin	United States	fractional quantum Hall effect
	Horst Störmer	United States, b. Germany	
	Daniel Tsui	United States, b. China	
1999	Gerardus ‘t Hooft	Netherlands	quantum structure of electroweak interactions in physics
	Martinus Veltman	Netherlands	

Year	Recipient(s)	Country	Work
2000	Zhores Alferov	Russia	semiconductor heterostructures in high-speed and opto-electronics
	Herbert Kroemer	United States, b. Germany;	semiconductor heterostructures in high-speed and opto-electronics;
	Jack St. Clair Kilby	United States	invention of integrated circuits
2001	Eric Cornell	United States	Bose-Einstein condensation of alkali atoms
	Wolfgang Ketterle	United States, b. Germany	
	Carl E. Wieman	United States	
2002	Raymond Davis Jr.	United States	detection of cosmic neutrinos;
	Masatoshi Koshiba	Japan	
	Riccardo Giacconi	United States, b. Italy	astrophysics and cosmic X-ray sources
2003	Alexei Abrikosov	United States, b. Russia	superconductivity and superfluids
	Vitaly Ginzburg	Russia	
	Anthony Leggett	United States, b. United Kingdom	
2004	David J. Gross	United States	asymptotic freedom and the theory of the strong interaction
	David H. Politzer	United States	
	Frank Wilczek	United States	
2005	Roy J. Glauber	United States	quantum theory of optical coherence;
	John L. Hall	United States	laser-based precision spectroscopy
	Theodor Hänsch	Germany	
2006	John C. Mather	United States	blackbody form and anistophy of cosmic microwave background radiation
	George F. Smoot	United States	
2007	Albert Fert	France	discovery of giant magneto-resistance resistance
	Peter Grunberg	Germany	

Source: Nobelprize.org.

* No prize awarded. Prize money allocated to the Special Fund of the Nobel Prize section for physics.

‡ No prize awarded. Prize money was allocated as follows: 1/3 to the Nobel Prize main fund, and 2/3 to the Special Fund of the Nobel Prize section for physics.

APPENDIX D

Nobel Laureates in Physiology or Medicine (1901–2007)

Nobel laureates are listed consecutively by year starting with 1901 and ending with 2007. The country indicates where the physician and/or researcher did major work. If their country of birth is different than where the major work was or is done, this is indicated after the "b." In a number of years, several physicians and or researchers shared the Nobel Prize for work in similar areas, either working collaboratively or independently, and their names are listed as such. When the prize has been shared for work in entirely different areas, the name, country, and work are shown as a separate entry.

Year	Recipient(s)	Country	Work
1901	Emil von Behring	Germany	serum therapy for diphtheria
1902	Ronald Ross	United Kingdom	discoveries related to malaria
1903	Niels R. Finsen	Denmark, b. Faroe Islands	treatment of diseases, mainly lupus, using light radiation
1904	Ivan Pavlov	Russia	work on physiology of digestion
1905	Robert Koch	Germany	discoveries related to tuberculosis
1906	Camillo Golgi	Italy	work on the structure of the nervous system
	Santiago Ramón y Cajal	Spain	
1907	Alphonse Laveran	France	disease-causing protozoa
1908	Ilya Mechnikov	Russia	work on immunity
	Paul Ehrlich	Germany	
1909	Theodor Kocher	Switzerland	physiology, pathology, and surgery of thyroid gland
1910	Albrecht Kossel	Germany	protein cell chemistry, including nucleic substances

(Continued)

Year	Recipient(s)	Country	Work
1911	Allvar Gullstrand	Sweden	dioptrics of the eye
1912	Alexis Carrel	France	vascular suture and transplantation of blood vessels and organs
1913	Charles Richet	France	work on anaphylaxis
1914	Robert Bárány	Austria	physiology and pathology of the vestibular apparatus
1915*			
1916*			
1917*			
1918*			
1919	Jules Bordet	Belgium	discoveries relating to immunity
1920	August Krogh	Denmark	capillary motor-regulating mechanism
1921*			
1922	Archibald V. Hill	United Kingdom	production of heat in the muscle;
	Otto F. Meyerhof	Germany	fixed relationship between oxygen consumption and metabolism of lactic acid in muscle
1923	Frederick Banting	Canada	discovery of insulin
	John J. R. Macleod	Canada	
1924	Willem Einthoven	Netherlands, b. Dutch East Indies	discovery of electrocardiogram
1925*			
1926	Johannes Fibiger	Denmark	discovery of Spiroptera carcinoma
1927	Julius Wagner-Jauregg	Austria	discovery of therapeutic value of malaria inoculation for dementia paralytica
1928	Charles Nicolle	France	work on typhus
1929	Christiaan Eijkman	Netherlands	discovery of antineuritic vitamin;
	Frederick Hopkins	United Kingdom	discovery of growth-stimulating vitamins
1930	Karl Landsteiner	United States and Netherlands b. Austria	discovery of human blood groups
1931	Otto Warburg	Germany	nature and mode of action of respiratory enzyme
1932	Charles Sherrington	United Kingdom	functions of neurons
	Edgar Adrian	United Kingdom	
1933	Thomas Morgan	United States	role of chromosomes in heredity
1934	George Whipple	United States	liver therapy in cases of anemia
	George Minot	United States	
	William Murphy	United States	

Year	Recipient(s)	Country	Work
1935	Hans Spemann	Germany	organizer effect in embryonic development
1936	Henry Dale	United Kingdom	chemical transmission of nerve impulses
	Otto Loewi	Austria	
1937	Albert Szent-Györgyi	Hungary	biological combustion processes, relative to vitamin C, and catalysis of fumaric acid
1938	Corneille Heymans	Belgium	sinus and aortic mechanisms in regulation of respiration
1939	Gerhard Domagk	Germany	discovery of antibacterial effects of prontosil (sulfa drug)
1940‡			
1941‡			
1942‡			
1943	Henrik Dam	Denmark	discovery of vitamin K;
	Edward Doisy	United States	discovery of chemical nature of vitamin K
1944	Joseph Erlanger	United States	differentiated functions of single nerve fibers
	Herbert Gasser	United States	
1945	Alexander Fleming	United Kingdom	discovery of penicillin
	Ernst Chain	United Kingdom, b. Germany	
	Howard Florey	United Kingdom	
1946	Hermann Muller	United States	production of mutations by means of X-ray irradiation
1947	Carl F. Cori	United States, b. Austria	catalytic conversion of glycogen;
	Gerty T. Cori	United States, b. Austria;	
	Bernardo Houssay	Argentina	role of pituitary lobe hormone in the metabolism of sugar
1948	Paul Müller	Switzerland	high efficiency of DDT as poison against certain arthropods
1949	Walter Hess	Switzerland	functional organization of inter-brain that coordinates activities of internal organs;
	Egas Moniz	Portugal	therapeutic value of leucotomy (lobotomy) in certain psychoses
1950	Edward Kendall	United States	structure and biological effects of hormones of adrenal cortex
	Tadeus Reichstein	Switzerland, b. Poland	
	Philip Hench	United States	

(Continued)

Year	Recipient(s)	Country	Work
1951	Max Theiler	United States, b. South Africa	discoveries concerning yellow fever and how to combat it
1952	Selman Waksman	United States, b. Russia	discovery of streptomycin
1953	Hans Krebs	United Kingdom, b. Germany;	discovery of citric acid cycle;
	Fritz Lipmann	United States, b. Germany	discovery of coenzyme A and importance for intermediary metabolism
1954	John Enders	United States	growth of poliomyelitis viruses in cultures of various types of tissues
	Thomas Weller	United States	
	Frederick Robbins	United States	
1955	Hugo Theorell	Sweden	nature and mode of action of oxidation enzymes
1956	André Cournand	United States, b. France	heart catheterization and pathological changes in circulatory system
	Werner Forssmann	Germany	
	Dickinson Richards	United States	
1957	Daniel Bovet	Italy, b. Switzerland	effects of synthetics on vascular system and skeletal muscles
1958	George Beadle	United States	genes that act by regulating definite chemical events genetic recombination and genetic material of bacteria
	Edward Tatum	United States	
	Joshua Lederberg	United States	
1959	Severo Ochoa	United States, b. Spain	biological synthesis of RNA and DNA
	Arthur Kornberg	United States	
1960	Frank M. Burnet	Australia	discovery of acquired immunological tolerance
	Peter Medawar	United Kingdom	
1961	Georg von Békésy	United States, b. Hungary	physical mechanism of stimulation within cochlea
1962	Francis Crick	United Kingdom	molecular structure of nucleic acids (DNA)
	James Watson	United States	
	Maurice Wilkins	United Kingdom	
1963	John Eccles	Australia	ionic mechanisms in peripheral and central portions of nerve cell membranes
	Alan Hodgkin	United Kingdom	
	Andrew Huxley	United Kingdom	
1964	Konrad Bloch	United States, b. Germany	mechanism and regulation of cholesterol and fatty acid metabolism
	Feodor Lynen	Germany	
1965	François Jacob	France	genetic control of enzyme and virus synthesis
	André Lwoff	France	
	Jacque Monod	France	

Year	Recipient(s)	Country	Work
1966	Peyton Rous	United States	discovery of tumor-inducing viruses
	Charles Huggins	United States	hormonal treatment of prostatic cancer
1967	Ragnar Granit	Sweden, b. Finland	primary physiological and chemical visual processes in the eye
	Haldan Hartline	United States	
	George Wald	United States	
1968	Robert Holley	United States	genetic code and function in protein synthesis
	HarGobind Khorana	United States, b. India	
	Marshall Nirenberg	United States	
1969	Max Delbrück	United States, b. Germany	replication mechanism and the genetic structure of viruses
	Alfred Hershey	United States	
	Salvador Luria	United States, b. Italy	
1970	Bernard Katz	United Kingdom	humoral transmitters in nerve terminals, and storage, release, and inactivation mechanisms
	Ulf von Euler	Sweden	
	Julius Axelrod	United States	
1971	Earl Sutherland, Jr.	United States	action of hormones
1972	Gerald Edelman	United States	chemical structure of antibodies
	Rodney Porter	United Kingdom	
1973	Karl von Frisch	Germany, b. Austria	organization and elicitation of individual and social behavior patterns
	Konrad Lorenz	Austria	
	Nikolaas Tinbergen	United Kingdom, b. Netherlands	
1974	Albert Claude	Belgium	structural and functional organization of the cell
	Christian de Duve	Belgium and United States	
	George Palade	United States, b. Romania	
1975	David Baltimore	United States	interaction between tumor viruses and the genetic material of the cell
	Renato Dulbecco	United Kingdom, b. Italy	
	Howard Temin	United States	
1976	Baruch Blumberg	United States	new mechanisms for the origin and dissemination of infectious diseases
	Carleton Gajdusek	United States	
1977	Roger Guillemin	United States, b. France	peptide hormone production of the brain;
	Andrew Schally;	United States, b. Poland;	
	Rosalyn Yalow	United States	radioimmunoassay of peptide hormones

(Continued)

Year	Recipient(s)	Country	Work
1978	Werner Arber	Switzerland	restriction enzymes and their application to problems of molecular genetics
	Daniel Nathans	United States	
	Hamilton Smith	United States	
1979	Allan M. Cormack	United States, b. South Africa	computer assisted tomography
	Godfrey Hounsfield	United Kingdom	
1980	Baruj Benacerraf	United States, b. Venezuela	genetically determined structures on cell surfaces that regulate immunological reactions
	Jean Dausset	France	
	George Snell	United States	
1981	Roger Sperry	United States	functional specialization of the cerebral hemispheres information processing in the visual system
	David Hubel	United States, b. Canada	
	Torsten Wiesel	United States, b. Sweden	
1982	Sune Bergström	Sweden	prostaglandins and related biologically active substances
	Bengt Samuelsson	Sweden	
	John R. Vane	United Kingdom	
1983	Barbara McClintock	United States	discovery of mobile genetic elements
1984	Niels Jerne	Switzerland, b. London (Danish citizen)	development and control of immune system and principle production of monoclonal antibodies
	Georges Köhler	Switzerland, b. Germany	
	César Milstein	United Kingdom, b. Argentina	
1985	Michael Brown	United States	regulation of cholesterol metabolism
	Joseph Goldstein	United States	
1986	Stanley Cohen	United States	discoveries of growth factors
	Rita Levi-Montalcini	Italy/United States, b. Italy	
1987	Susumu Tonegawa	United States, b. Japan	genetic principle for generation of antibody diversity
1988	James W. Black	United Kingdom	discoveries of important principles for drug treatment
	Gertrude Elion	United States	
	George Hitchings	United States	
1989	J. Michael Bishop	United States	cellular origin of retroviral oncogenes
	Harold Varmus	United States	
1990	Joseph Murray	United States	organ and cell transplantation in treatment of human disease
	E. Donnall Thomas	United States	

Year	Recipient(s)	Country	Work
1991	Erwin Neher	Germany	function of single ion channels in cells
	Bert Sakmann	Germany	
1992	Edmond Fischer	United States, b. China	reversible protein phosphorylation as a biological regulatory mechanism
	Edwin Krebs	United States	
1993	Richard Roberts	United States, b. United Kingdom	discoveries of split genes
	Phillip Sharp	United States	
1994	Alfred Gilman	United States	G-proteins and their role in signal transduction in cells
	Martin Rodbell	United States	
1995	Edward Lewis	United States	genetic control of early embryonic development
	Christiane Nüsslein-Volhard	Germany	
	Eric Wieschaus	United States	
1996	Peter Doherty	United States, b. Australia	specificity of the cell-mediated immune defense
	Rolf Zinkernagel	Switzerland	
1997	Stanley Prusiner	United States	discovery of Prions
1998	Robert Furchgott	United States	nitric oxide as a signaling molecule in the cardiovascular system
	Louis Ignarro	United States	
	Ferid Murad	United States	
1999	Günter Blobel	United States, b. Germany	intrinsic signals of proteins that govern their transport and localization in the cell
2000	Arvid Carlsson	Sweden	signal transduction in the nervous system
	Paul Greengard	United States	
	Eric Kandel	United States, b. Austria	
2001	Leland Hartwell	United States	key regulators of the cell cycle
	R. Timothy Hunt	United Kingdom	
	Paul M. Nurse	United Kingdom	
2002	Sydney Brenner	United Kingdom, b. South Africa	genetic regulation of organ development and programmed cell death
	H. Robert Horvitz	United States	
	John Sulston	United Kingdom	
2003	Paul Lauterbur	United States	magnetic resonance imaging
	Peter Mansfield	United Kingdom	
2004	Richard Axel	United States	odorant receptors and the organization of olfactory system
	Linda Buck	United States	
2005	Barry Marshall	Australia	discovery of *Heliobacter pylori* in gastric and peptic ulcer disease
	J. Robin Warren	Australia	

(Continued)

Year	Recipient(s)	Country	Work
2006	Andrew Fire	United States	RNA interference-gene silencing by double-stranded RNA
	Craig Mello	United States	
2007	Mario Capecchi	United States, b. Italy	gene modifications in mice by the use of embryonic stem cells
	Martin Evans	United Kingdom	
	Oliver Smithies	United States, b. United Kingdom	

Source: Nobelprize.org.

* No prize awarded. Prize money allocated to the Special Fund of the Nobel Price section for physiology or medicine.

‡ No prize awarded. Prize money was allocated as follows: 1/3 to the Nobel Prize main fund, and 2/3 to the Special Fund of the Nobel Prize section for physiology or medicine.

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