CHAPTER 6

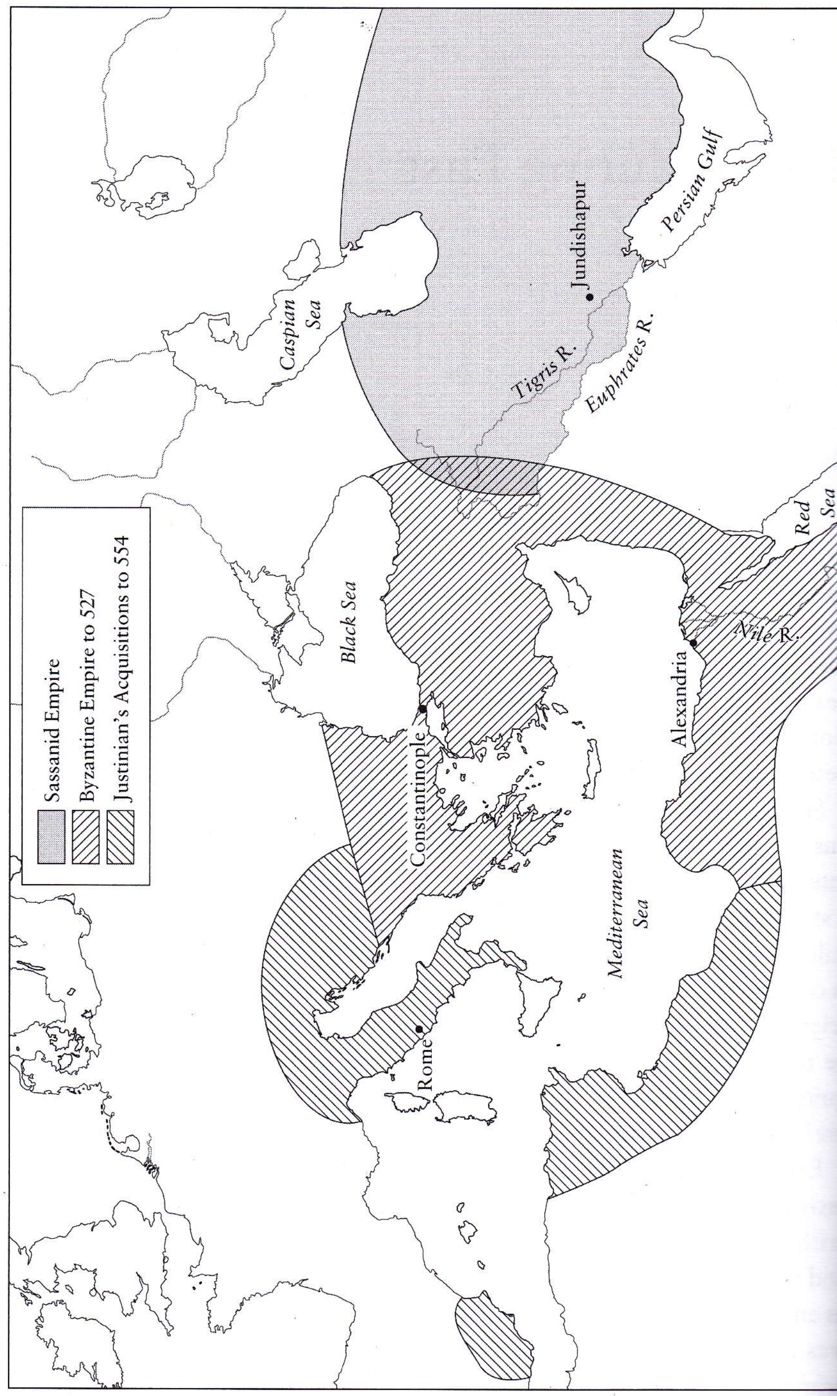
The Enduring East

Byzantine Orthodoxy

After Rome fell in 476 CE, the empire's eastern districts with their capital at Constantinople gradually metamorphosed into the Greek-speaking Byzantine Empire (see map 6.1). A Christian state, headed by an emperor and governed by elaborate and scheming bureaucracies (hence "byzantine"), the Byzantine Empire endured for a thousand years before being overrun by the Ottoman Turks in 1453. In possession of the Egyptian breadbasket the empire flourished and wealthy emperors continued to patronize many old institutions of higher learning.

Science in the Byzantine Empire remains to be studied by historians in greater detail. Byzantine civilization is often criticized as anti-intellectual and stifled by a mystical Christianity that was imposed as a state religion. That the emperor Justinian (r. 527–565) closed Plato's still-functioning Academy at Athens along with other schools in 529 CE is commonly seen as evidence of the state's repressive posture toward science. Yet, to dismiss Byzantium from the history of science would be to overlook continuations of Hellenistic traditions and the ways, quite typical of eastern bureaucratic civilizations, in which science and useful knowledge became institutionalized in society.

Even after the Justinian closures, state schools and church schools provided instruction in the mathematical sciences (the quadrivium: arithmetic, geometry, astronomy, and music), the physical sciences, and medicine; libraries existed as centers of learning. The true hospital, as an institution of in-patient medical treatment (and Christian mercy), was a notable Byzantine innovation. It was, like the hospital today, primarily a center of medical technology, not science. As hospitals arose throughout the Byzantine Empire through the largesse of government, church, and aristocratic patrons, in some measure they also became centers of medical research. Byzantine medicine fully assimilated the medical and physiological teachings of Galen and Hippocrates,



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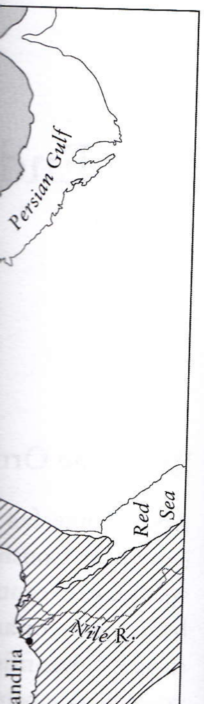


while some hospitals maintained libraries and teaching programs and even fostered some original investigations and innovative techniques. Learned Byzantine doctors turned out influential medical and pharmacological tracts, albeit with much repetition of Greek knowledge. Veterinary medicine was a notable aspect of scientifico-medical activity in Byzantine civilization, one heavily supported by monarchs who had an interest in the well-being of their war horses since cavalry and the cavalry charge formed the basis of the Byzantine army and military tactics. As a result, Byzantine veterinarians produced many veterinary manuals, occasionally on a high level of originality.

In the fields of the exact sciences the Greek-speaking Byzantine scholars inherited much Greek learning from antiquity. They knew their Aristotle, Euclid, and Ptolemy, and Byzantine astronomers and mathematicians themselves sometimes produced sophisticated tracts based on earlier Greek and contemporary Persian sources. In addition to calendar work, a strong element of astrology, reflecting that venerable and inextinguishable desire to know the future, characterized Byzantine astronomy. Experts likewise studied music and mathematical music theory, perhaps for liturgical purposes. And finally, Byzantine alchemy and alchemical mineralogy cannot be overlooked as areas of both considerable research activity and of perceived practical utility.

The most notable natural philosopher of the early Byzantine era was John Philoponus. A Christian, Philoponus lived and worked in Alexandria under Byzantine governance during the middle years of the sixth century CE, and he launched the most sweeping attack on Aristotelian physics prior to the Scientific Revolution in Europe. In various commentaries he developed trenchant critiques of Aristotle and several aspects of Aristotelian physical theory. In his ingenious analysis of projectile motion, for example—motion Aristotle had lamely explained by invoking the ambient air as the required mover—Philoponus suggested that the thrower endowed the projectile with a certain power to move itself. Philoponus's views in turn sparked critical responses from other commentators, and because he so focused the debate on specific problems in Aristotle's writings on natural philosophy, Philoponus was later influential among Islamic and European natural philosophers when they came to review Aristotle's work. Having studied the science of the Greeks and writing in Greek, his career and his accomplishments are landmarks in the tradition of Byzantine science.

A full social history of Byzantine science would display the subject in a more favorable light than does intellectual history alone, which stresses originality and pure theory. Such a social history would pay close attention to intellectually unambitious medical tracts, to treatises published by veterinary surgeons retained by Byzantine monarchs, to the many farmers' manuals and herbals produced under Byzantine governance, as well as to astrology and alchemy. In a society where

Map 6.1. (*opposite*) Byzantium and Sassanid Persia. In late antiquity two derivative civilizations took root in the Middle East—the Byzantine Empire centered in Constantinople and Sassanid Persia in the heartland of ancient Mesopotamia. Both assimilated ancient Greek science and became centers of learning.

bureaucratic centralization was extreme, support came precisely for encyclopedists, translators, and writers of manuals on subjects useful and mundane. And it is precisely the kind of work that historians intent on detecting theoretical novelty tend to neglect.

The loss of Egypt and the productive resources of the Nile Valley to invading Arabs in the seventh century was a severe setback to the economy and society of Byzantium. Yet a reduced Byzantine civilization maintained itself, its cities, its institutions, and its science for hundreds of years. Inevitably, however, decline set in after the year 1000, as Byzantium faced challenges from the Turks, from the Venetians, and from friendly and not-so-friendly European Christians on crusade. In 1204 Crusaders pillaged Constantinople and occupied it until 1261. Finally, in 1453 the city and the empire fell to the Turks. The story of science in the empire of the Ottoman Turks that followed is a chapter being written by up-and-coming scholars.

Although Byzantium never became a center of significant original science, it did not repudiate the tradition of secular Greek learning. Indeed, it tolerated and even preserved that tradition alongside the official state religion of Christianity.

Mesopotamia Revisited

In the heartland of ancient Mesopotamia the Sassanid dynasty created a typical Near Eastern system of scientific institutions along with a typical Near Eastern economy based on hydraulic agriculture and the restoration and maintenance of the old irrigation systems. The Sassanid dynasty was founded in 224 CE, and was characterized by a strong central government and a bureaucratic caste that included scribes, astrologers, doctors, poets, and musicians. By the sixth century the royal residence at Jundishapur, northeast of present-day Basra, had become a cultural crossroads where many different learned traditions mingled: Persian, Christian, Greek, Hindu, Jewish, and Syrian. Persian cultural life became enriched when Nestorian Christians—bringing Greek learning with them—fled Byzantium after their center at Edessa in Turkey was shut down in 489. A significant translation effort, centered in Jundishapur, rendered Greek texts into Syriac, the local language. Texts deemed to contain useful knowledge were generally chosen for translation—mainly the medical arts, but also scientific subjects, including Aristotle's logical tracts, mathematics, and astronomy. Jundishapur also became the site of a hospital and medical school, enriched by the presence of Indian medical masters; later taken over by Arab-Islamic caliphs, the medical school at Jundishapur continued to flourish until the eleventh century. Persian government authorities also sponsored astronomical and astrological investigations. While recent reappraisals have tempered its importance, Jundishapur was nonetheless a cosmopolitan intellectual center and a center of scientific patronage for several centuries before Persia fell to the forces of Islam in 642 CE.

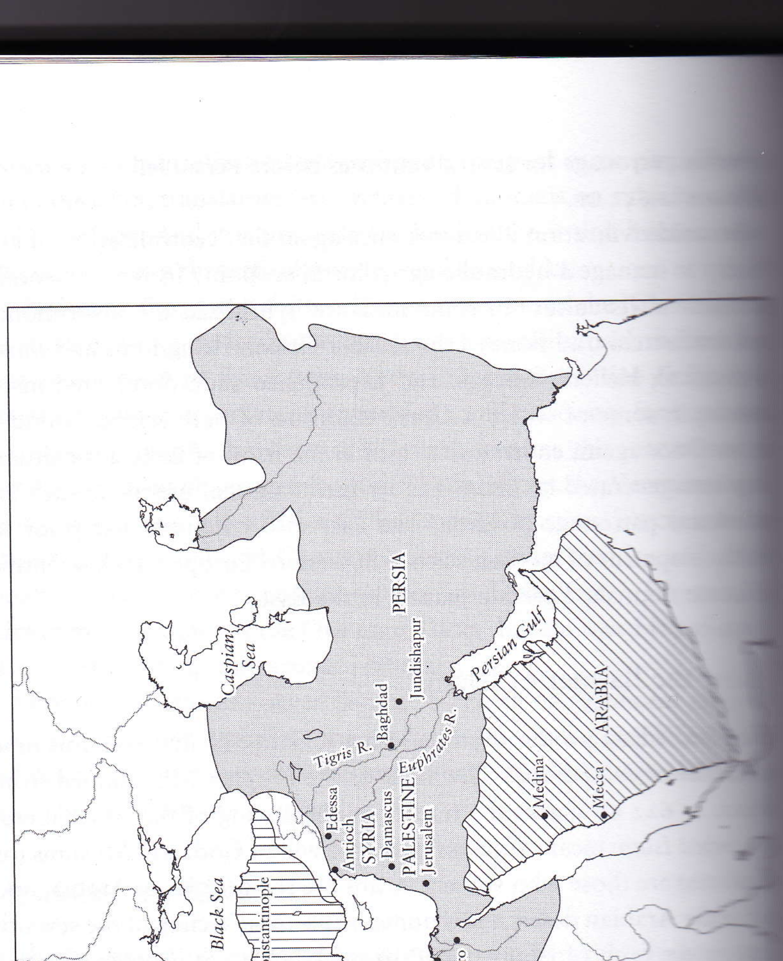
Sassanid civilization illustrates once again that centralization of authority to manage a hydraulic agricultural economy fostered scientific institutions. Its culture in some measure hybridized the institutional and intellectual traditions of the ancient Oriental kingdoms and those of classical, Hellenic Greece, and it produced state-dominated institutions, in some of which a Greek tradition of pure science found a niche. Once again, enormous wealth in the form of large agricultural surpluses generated by intensified irrigation agriculture made such institutional patronage possible. The case also confirms that prior to the development of modern science in western Europe Greek scientific influence flourished predominantly in the East.

Under the Banner of Islam

The Middle East produced still another scientific civilization, this time under the aegis of Islam. The flight of the Prophet Mohammed from Mecca in 622 CE marks the traditional beginning of the Muslim era. The word *Islam* means submission to the will of God, and Muslims (or Moslems) are those who submit. Arabs are the peoples of Arabia, and out of the Arabian desert and a nomadic pastoral society of the seventh century the faith of Islam spread to many different peoples east and west. Within three decades Islamic armies conquered Arabia, Egypt, and Mesopotamia—replacing Persian power and severely reducing the Byzantine Empire. In slightly more than a century they established an Islamic commonwealth stretching from Portugal to Central Asia. A unified sociocultural domain, Islam prospered as a great world civilization, and its scientific culture flourished for at least five centuries.

The success of Islam depended as much on its faithful farmers as on its soldiers. The former took over established flood plains in Mesopotamia and Egypt, and in what amounted to an agricultural revolution they adapted new and more diversified food crops to the Mediterranean ecosystem: rice, sugar cane, cotton, melons, citrus fruits, and other products. With rebuilt and enlarged systems of irrigation, Islamic farming extended the growing season and increased productivity. That Islamic scientists turned out an uninterrupted series of treatises on agriculture and irrigation is one indication of the importance of these endeavors. So, too, are the specialized treatises on camels, horses, bees, and falcons, all animals of note for Islamic farmers and Islamic rulers.

The effects of such improved agricultural productivity were typical: unprecedented population increases, urbanization, social stratification, political centralization, and state patronage of higher learning. Baghdad, founded in 762 on the Tigris, became the largest city in the world in the 930s with a population of 1.1 million. Córdoba in southwestern Spain reached a population close to 1,000,000 under Islamic rule,



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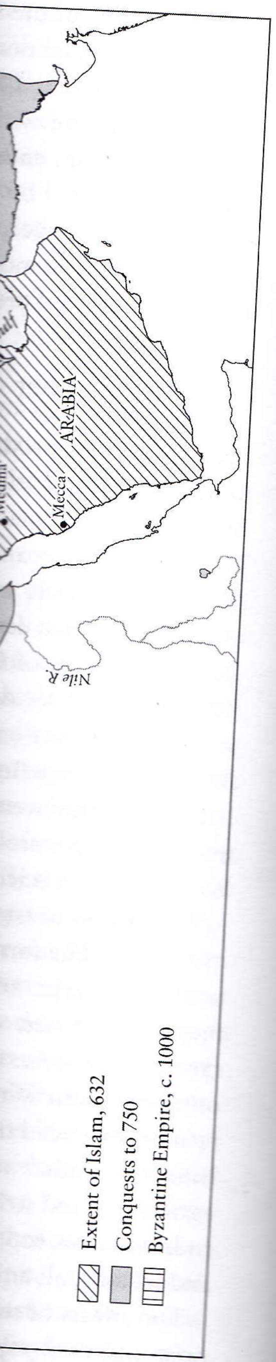

and several other Islamic cities had populations between 100,000 and 500,000 during a period when the largest European cities had populations numbering fewer than 50,000.

Islam was and is based on literacy and the holy book of the Quran (Koran); and, although policy vacillated, Islam showed itself tolerant toward Christians and Jews, also "people of the book." Thus, in contrast to the barbarian farmers of Europe who pillaged and destroyed the high civilizations they encountered, the nomadic and pastoral Arabs established conquest empires by maintaining and assimilating the high cultures they encountered. Early Islamic rulers encouraged the mastery of foreign cultural traditions, including notably Greek philosophy and science, perhaps in order to bolster the logical and rhetorical position of their new religion in the face of more highly developed religions and critical intellectual traditions. The result was another hybrid society, the cultural "hellenization" of Islam and its typically bureaucratized institutions, funded by wealthy monarchs and patrons who encouraged useful knowledge along with a dash of natural philosophy.

Medieval Islam became the principal heir to ancient Greek science, and Islamic civilization remained the world leader in virtually every field of science from at least 800 to 1300 CE. The sheer level of scientific activity makes the point, as the number of Islamic scientists during the four centuries after the Prophet matched the number of Greek scientists during the four centuries following Thales. Islamic scientists established the first truly international scientific community, stretching from Iberia to Central Asia. Yet, despite considerable scholarly attention, medieval Islamic science is sometimes still dismissed as a conduit passively "transmitting" ancient Greek science to the European Middle Ages. A moment's thought, however, shows how ahistorical it is to evaluate the history of Islamic science only or even largely as a link to European science, or even to subsume Islamic science into the "Western tradition." Medieval Islam and its science must be judged on their own terms, and those terms are as much Eastern as Western.

Only a small fraction of Islamic scientific texts have been published. Most remain unstudied and in manuscript. Scholarly emphasis to date has been on classic texts, on the "internal" history of scientific ideas, on biographies, and on "precursor-itis," or identifying Arabic scientists who were precursors of ideas that were of later importance to European science. The institutional aspects of Islamic science are only beginning to be studied with scholarly rigor, and nothing like a full historical survey exists for the Islamic case.

Furthermore, the field divides into two divergent interpretative schools. One school argues for a "marginality" thesis, holding that the secular, rational sciences inherited from Greek civilization—known in Islam as the "foreign" (*aw'il*) sciences—never became integrated into Islamic culture, remaining only on the cultural margins, tolerated at best, but never a fundamental part of Islamic society. The "assimila-

Map 6.2. (opposite) Islam. Following the birth of Islam in the seventh century, the Islamic conquest stretched from the Atlantic Ocean almost to the borders of China. In capturing Egypt and the resources of the Nile, the forces of Islam dealt a severe blow to Byzantine civilization.

tionist" school, on the other hand, contends that the foreign sciences became woven into the fabric of Islamic life. Neither interpretation quite fits the facts, but the presentation favored here leans toward the assimilationists, especially in tracing the institutional basis of Islamic science and in recognizing a similarity between the social function of science in Islam and in other Eastern civilizations.

Islamic scientific culture originated through the effort to master the learning of more established civilizations, and that first required the translation of documents into Arabic. Given the early conquest of Jundishapur, Persian and Indian influences, rather than Greek, were more influential in the early stages of Islamic civilization. Already in the 760s, for example, an Indian mission reached Baghdad to teach Indian science and philosophy and to aid in translations of Indian astronomical and mathematical texts from Sanskrit into Arabic. Later, Muslim men of science traveled to India to study with Indian masters.

In the following century, however, the translation movement came to focus on Greek scientific works. The governing caliph in Baghdad, Al-Ma'mun, founded the House of Wisdom (the *Bayt al-Hikma*) in 832 CE specifically as a center of translation and mastery of the secular foreign sciences. Al-Ma'mun sent emissaries to collect Greek scientific manuscripts from Byzantine sources for the House of Wisdom where families of scholar-translators, notably Ishāq ibn Hunayn and his relatives, undertook the Herculean task of rendering into Arabic the Greek philosophical and scientific tradition. As a result, virtually the entire corpus of Greek natural science, mathematics, and medicine was brought over into Arabic, and Arabic became the international language of civilization and science. Ptolemy's *Almagest*, for example—the very title, *al-Mageste*, is Arabic for "the greatest"—appeared in several translations in Baghdad early in the ninth century, as well as Euclid's *Elements*, several works of Archimedes, and many of Aristotle, beginning with his logical treatises. Aristotle became the intellectual godfather of Islamic theoretical science, spawning a succession of commentators and critical thinkers. A measure of the effort expended on translating Greek texts is that, even now, more Aristotelian writings—the works of Aristotle and his Greek commentators—supposedly are available in Arabic than in any European language.

Al Ma'mun supported his translators and the House of Wisdom, not merely out of the love of learning, but for practical utility deemed directly useful to the monarch, notably in such fields as medicine, applied mathematics, astronomy, astrology, alchemy, and logic. (Aristotle became assimilated initially for the practical value of his logic for law and government, and only later did the entire body of his scientific and philosophical works find its way into Arabic.) Medicine was the primary field naturalized by Islamic translators; Ishāq ibn Hunayn alone supposedly translated 150 works of Galen and Hippocrates. Thus, by

900 CE, while Europe possessed perhaps three works of Galen, transcribed by solitary scholars, Islam had 129 produced under government patronage. The basis had been established for a great scientific civilization.

In the Islamic world the secular sciences were generally not valued for their own sakes, but rather for their utility; secular knowledge was normally not pursued by individualistic natural philosophers as an end in itself as in Hellenic Greece or later in Christian Europe. To this extent, the "marginality" thesis provides a degree of insight into the place of pure science in Islamic society. Nevertheless, such a view slights the ways in which science became patronized and institutionalized in a variety of social niches in Islamic culture. As social history, the "assimilationist" thesis more properly portrays the role and institutionalized character of science and natural knowledge in Islam.

Each local mosque, for example, was a center of literacy and learning, albeit largely religious. But mosques also had official timekeepers (the *muwaqqit*) who set times for prayer. This recondite and exact procedure could only be effected by competent astronomers or at least trained experts. Thus, for example, afternoon prayers occur when the shadow of an object equals the length of its shadow at noon plus the length of the object. Several esoteric geographical and seasonal factors determine these times, and the *muwaqqit* used elaborate timekeeping tables, some with upwards of 30,000 entries, supplemented by instruments such as astrolabes and elaborate sundials to ascertain when prayer should take place. (The astrolabe became a highly developed instrument capable of solving 300 types of problems in astronomy, geography, and trigonometry.) Similarly, the faithful prayed in the direction of Mecca, and therefore geographical knowledge also had to be applied locally to discover that direction. Astronomers determined the beginning of Ramadān, the month-long period of daily fasts, and the hour of dawn each day. Along these lines, each local Islamic community possessed mathematically and legally trained specialists, the *faradi*, who superintended the division of inheritances.

The Islamic legal college, or *madrasa*, was an institution of higher learning wherein some "foreign sciences" were taught. Widespread throughout the Islamic world, the madrasa was primarily an advanced school for legal instruction in the "Islamic sciences"—law, not theology, being the preeminent science in Islam. The madrasa should not be equated with the later European university, in that the madrasa was not a self-governing corporation (prohibited in Islam). It did not maintain a standard curriculum, and it did not confer degrees. Technically a charitable endowment rigidly bound by its founding charter and prohibited from teaching anything contrary to the fundamental tenets of Islam, the madrasa operated more as an assemblage of independent scholars with whom students studied on an individual basis and where instruction emphasized memorization, recitation, and mastery of authoritative texts. Endowments supported instructors and paid the tuition, room, and board of students.

The secular sciences found a niche in these institutions of higher learning. Logic, for example, was taken over from Greek traditions, and arithmetic was studied for the purposes of training the *faradi* or experts for handling inheritances. Similarly, geometry, trigonometry, and astronomy, although tightly controlled, likewise came within the fold of Islamic studies because of the religious needs of determining proper times for prayer and the direction of Mecca. While not publicly professed, specialists also offered private instruction in the "foreign sciences" outside the formal setting of the madrasa. And secular scientific and philosophical books could be found in public libraries associated with madrasas and mosques. In a word, then, the student who wished to learn the natural sciences could do so at a high level of sophistication in and around the institution of the madrasa.

The library formed another major institution of Islamic civilization wherein the natural sciences were nurtured. Often attached to madrasas or mosques, usually staffed by librarians and open to the public, hundreds if not thousands of libraries arose throughout the Islamic world. Córdoba alone had seventy libraries, one containing between 400,000 and 500,000 volumes. Thirty madrasas existed in Baghdad in the thirteenth century, each with its own library, and 150 madrasas operated in Damascus in 1500 with as many libraries. The library deep in Islamicized Africa at Timbuktu in Mali held 30,000 tomes. The library attached to the observatory in Maraghah reportedly contained 400,000 volumes. Another House of Wisdom (the *Dār al-'ilm*) in tenth-century Cairo contained perhaps 2 million books, including some 18,000 scientific titles. One collector boasted that it would take 400 camels to transport his library; the estate of another included 600 boxes of books, manhandled by two men each. The tenth-century Persian physician Ibn Sīnā (980–1037), known in the West as Avicenna, writing in Arabic left an account of the impressive quality of the royal library in Muslim Bukhara on the Asian outskirts of Islam:

> I found there many rooms filled with books which were arranged in cases, row upon row. One room was allotted to works on Arabic philology and poetry, another to jurisprudence and so forth, the books on each particular science having a room to themselves. I inspected the catalogue of ancient Greek authors and looked for the books which I required; I saw in this collection books of which few people have heard even the names, and which I myself have never seen either before or since.

In sharp contrast, libraries in medieval Europe numbered only hundreds of items, and as late as the fourteenth century the library collection at the University of Paris contained only 2,000 titles, while a century later the Vatican library numbered only a few hundred more.

But the love of learning alone could not have accounted for Islamic libraries. The formation of huge collections was clearly dependent on the willingness of caliphs and wealthy patrons to underwrite the costs. It was also dependent on paper-making, a new technology acquired from the Chinese in the eighth century which allowed the mass production of paper and much cheaper books. Paper factories appeared in Samarkand after 751, in Baghdad in 793, in Cairo around 900, in Morocco in 1100, and in Spain in 1150. In Baghdad alone 100 shops turned out paper books. Ironically, when the printing press appeared in the fifteenth century Islamic authorities banned it for fear of defiling the name of God and to prevent the proliferation of undesirable materials.

Although astronomers had previously observed the heavens, Islamic civilization created a new and distinctive scientific institution: the formal astronomical observatory. Underwritten by ruling caliphs and sultans, observatories, their equipment, and staffs of astronomers discharged several practical functions. Astronomers prepared increasingly accurate astronomical handbooks (*zij*) for calendrical and religious ends—to fix the times of prayer and of religious observances such as Ramadan. The Islamic calendar was a lunar calendar, like that of ancient Babylonia, of 12 months of 29 or 30 days unfolding over a 30-year cycle, with trained observers determining when the new moon commenced. Geography was also closely connected to astronomy and, beginning with Ptolemy's *Geography*, Muslim astronomers developed navigational and geographical techniques serviceable to both sailors and desert travelers.

Islamic authorities formally distinguished between astronomy as the study of the heavens and astrology as investigating heavenly influence on human affairs. The distinction may have facilitated the social integration of astronomy, but the strongest single motive behind royal patronage of astronomy remained the putative divinatory power of astrology. Despite its occasional condemnation by religious authorities on the grounds that it misdirected piety toward the stars rather than God, astrology remained the most popular of the secular sciences, and it flourished especially in court settings, where regulations and exams fixed the qualifications, duties, and salaries of astrologers. Elsewhere, the local chief of police regulated astrology as a marketplace activity. Along with Ptolemy's *Almagest*, Muslim astronomers/astrologers had available his astrological treatise, the *Tetrabiblos*, and many used it and like volumes to cast horoscopes and gain patronage as court astrologers.

Observatories arose throughout the Muslim world. Al-Ma'mun founded the first around 828 in Baghdad. The best known, established in 1259, was the observatory at Maraghah in a fertile region near the Caspian Sea. It was formed in part to improve astrological prediction. A substantial library was attached to the observatory and actual in-

Fig. 6.1. An astrolabe. This multifaceted device was invented in the Islamic world to facilitate astronomical observation and to solve problems relating to timekeeping, geography, and astronomy.

struction in the sciences was offered there with government support. Expert astronomers made up what can only be called the Maraghah school, and such men as al-Tūsī (d. 1274), al-Shīrāzī (d. 1311), and their successor, Ibn al-Shātir (d. 1375), far surpassed ancient astronomy and astronomical theory in perfecting non-Ptolemaic (although still geocentric) models of planetary motion and in testing these against highly accurate observation. But, the observatory at Maraghah, like many others, proved short-lived, lasting at most 60 years. Even though protected by non-Islamic Mongol rulers, the Maraghah observatory and several other Islamic observatories were closed by religious reaction against impious study of astrology.

Farther north and east, in fifteenth-century Samarkand, sustained by irrigated orchards, gardens, and cropland, the celebrated Muslim scholar-prince Ulugh Beg (1393–1449) founded a madrasa and an

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jor observatory. The importance that Islamic astronomers attached to the precision of their observations necessitated the use of exceptionally large instruments, such as the three-story sextant at Samarkand with a radius of 40 meters (132 feet). These large instruments, along with the observatory structures, the staffs of astronomers and support personnel, and their affiliated libraries entailed costs so high that they could only be met through government support. Through its observatories medieval Islam established a tradition of observational and theoretical astronomy unequaled until the achievements of European science in the sixteenth and seventeenth centuries.

Islamic mathematics, while justly renowned, consistently displayed a practical trend in its emphasis on arithmetic and algebra rather than on the formal theoretical geometry of the Greeks. Medieval Islamic mathematicians also developed trigonometry, which greatly facilitated working with arcs and angles in astronomy. The adoption of easily manipulated "Arabic numerals" from Indian sources further reflects this practical orientation. While Islamic mathematicians solved what were, in effect, higher-order equations, many problems had roots in the practical world dealing with taxes, charity, and the division of inheritances. The ninth-century mathematician al-Khwarizmi, for example, who originally introduced "Arabic numerals" from India, wrote a manual of practical mathematics, the *al-Jabr* or what came to be known in the West as the *Algebra*. Not coincidentally, al-Khwarizmi worked at the court of al-Ma'mun.

Islamic medicine and its institutionalized character deserve special attention. The Arabs had their own medical customs, and the Quran (Koran) contains many sayings of the Prophet regarding diet, hygiene, and various diseases and their treatment. The Arabic translation movement made available to physicians all of the Hippocratic canon and the works of Galen, notably through the texts of ancient Greek medicine preserved at Alexandria. Islamic medicine also assimilated Persian and Indian traditions, in part from having taken over the medical school at Jundishapur and in part from direct contact with India through the drug and perfume trades. The resulting medical amalgam became thoroughly naturalized and integrated into the social fabric of Islam.

A handful of madrasas specialized in medical training, but the hospital became the primary institutional locus of Islamic medicine. Government-supported hospitals existed throughout the Islamic world, with especially notable medical centers in Baghdad, which eclipsed Jundishapur, Damascus, which saw the foundation of six hospitals between the thirteenth and fifteenth centuries, and Cairo. Many hospitals came to possess elaborate medical staffs, specialized medical wards, attached medical libraries, and lecture halls (*majlis*). Islamic hospitals thus evolved as centers of teaching and research, as well as dispensaries of medical treatment, including medical astrology. And, whereas guilds and corporate structures were never recognized in Islamic societies, governments licensed physicians through local police officials. Islamic doctors, such as al-Rāzī (Rhazes, 854–925), al-Majūsī (Haly Abbas, d. 995), Ibn Sīnā (Avicenna), and others engaged in medical experimentation and developed unprecedentedly sophisticated and expert understanding of diseases and medical treatments.

The medical dimension may help explain a particular strength of Islamic science in optics. Especially in Egypt, where desert conditions contributed to eye ailments, a strong medical literature developed in ophthalmology, and Islamic physicians became expert in the treatment of the eye and the anatomy and physiology of vision. Although not a physician, the great Islamic physicist Ibn al-Haytham (Alhazen, 965–1040) worked in Egypt and wrote on eye diseases. His *Optics* is only the best known and most influential of a series of Islamic scientific works—many with an experimental approach—concerned with vision, refraction, the camera obscura, burning mirrors, lenses, the rainbow, and other optical phenomena.

Physicians enjoyed high public regard, and many Muslims who made scientific and philosophic contributions earned their living as court physicians or court-appointed administrators and legal officials. For example, Averroës (Ibn Rushd, 1126–98), known as "The Commentator" on Aristotle, worked as a court physician and religious jurist in Spain. The Islamic polymath Avicenna (Ibn Sīnā), renowned as the "Galen of Islam," accepted patronage as a physician in various courts in order to pursue philosophy and science. The noted Jewish philosopher and savant Moses Maimonides (Musa ibn Maymun, 1135–1204) acted as physician to the sultan at Cairo. In a word, court patronage provided institutionalized positions where physician-scientists could master and extend the secular sciences, and court positions afforded a degree of insulation from the dominant religious institutions and the supremacy of religious law in Islamic society at large.

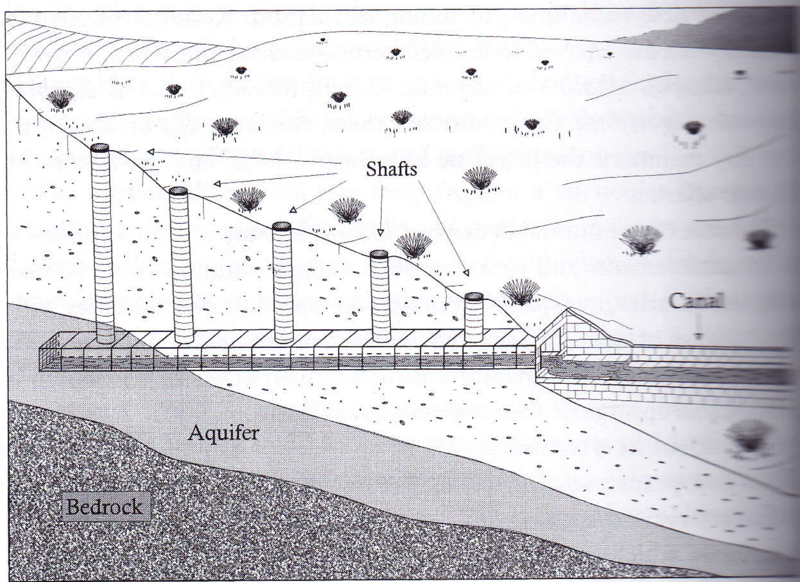
Closely associated with courts and the patronage of rulers, a highly developed tradition of Islamic alchemy involved many scientists. Alchemy ranked among the sciences, being derived from Aristotle's matter theory. In the search for elixirs of immortality, Islamic alchemy also seems to have been influenced by Chinese alchemy, and it likewise subsumed work on mineralogy, which showed Indian and Iranian influences. Alchemy was a secret art, and adepts attributed some 3,000 alchemical texts to the founder of Islamic alchemy, the ninth-century figure Jābir ibn Hayyān, known as Geber in the Latin West. On one level, no doubt the one most appreciated by patrons, the transformation of base metals into gold and the creation of life-giving elixirs represented the goals of alchemy. To many practitioners, however, Islamic alchemy became a highly intellectual endeavor that primarily involved the spiritual refinement of the individual alchemist. In pursuing their science, Islamic alchemists invented new equipment and perfected new techniques, including distillation. Residues of Islamic alchemy remain in Arabic-derived terms, such as the word *alchemy* itself, *alcohol*, *alkali*, and *alembic*. Indeed, in such terms as *algebra*, *azimuth*, *algorithm*, and a host of others, the language of science to this day maintains the linguistic imprint of Arabic and the history of Islamic science.

The sheer institutional density of Islamic science accounts for some of its achievements and characteristics. Scholars and scientists staffed schools, libraries, mosques, hospitals, and especially observatories with their teams of astronomers and mathematicians. The opportunities and support that these institutions offered men of science produced a remarkable upsurge of scientific activity, as measured by the number of Islamic scientists which surpassed by an order of magnitude the handful of Europeans pursuing science before 1100 CE. Another result was a characteristic research profile, like that of the ancient bureaucratic kingdoms, which exaggerated utility, public service, and the interests of the state.

Technology and industry in medieval Islam gave as little to and received as little from the realm of science as they had in the Greco-Roman world. Islamic science embraced much of ancient Greek learning, as we have seen, but Islamic technology remained more akin to that of Rome and the eastern kingdoms. In architecture the Muslims employed the Roman arch rather than the Greek post and lintel system of building. And agriculture depended heavily on hydraulic engineering as it had in the Roman provinces and in all civilizations in the Near East. Indeed, the Islamic conquest maps closely onto regions that lent themselves to hydraulic intensification; Greece and Italy, where artificial irrigation was less important, did not become Islamicized, while Spain saw a dramatic development of hydraulic technology under Muslim rule. The construction of large dams, waterwheels, and qanats (underground channels with earthenware pipes designed to tap ground water) all formed part of the Islamic engineering repertoire. In Africa, Islamic centers at the walled city of Khartoum and at Timbuktu were situated near water sources. In Iran qanats supplied fully half of the water used for irrigation and urban needs. Such were the feats of craftsmen and artisans divorced from the bookish worlds of theology and science.

Scholars disagree on when the vitality of scientific activity started to decline in the Islamic world. Some say that the decline began after the twelfth century, especially in the Western regions; others say that important new science continued to be done in the East until the fifteenth and sixteenth centuries. However, no one denies that Islamic science and medicine reached their historical golden age in the centuries surrounding the year 1000 and that decline in the creative level of original work eventually set in. It should be noted that such a consensus

Fig 6.2. Qanat technology. Artificial irrigation sustained Islamic agriculture and civilization. Islamic engineers developed sophisticated hydraulic techniques, including qanats, which tapped underground water sources.



has tended to obscure the ways in which knowledge in mosques and madrasas continued to function in Islamic society for centuries, irrespective of any "decline" in the quality of original science. That point notwithstanding, several suggestions have been offered to account for the eventual decline of the Islamic scientific traditions, all of them external and sociological, for nothing in the internal logic of scientific ideas can account for the loss of vigor of Islamic science.

The main thesis has centered on the ultimate triumph of religious conservatives within Islam. As a religion, Islam emphasizes submission before the divine and unknowable nature of God/Allah. Thus, according to the "marginality" thesis, the cultural values and legal tenets of Islam proved such that secular philosophy and learning were always suspect to varying degrees and remained peripheral to the mainstream of Islamic society. Individual jurists and religious leaders, for example, could and did sometimes issue religious rulings (*fatwas*) for impiety against those who became too expert in the secular sciences. Different factions within Islam contended over the value of human reason and rationality in pursuing understanding, but ultimately, so the argument goes, religious conservatives prevailed, and with increasing intolerance the creative spirit of Islamic science evaporated. Why it flourished and why it declined when it did lie beyond the reach of marginalist explanations.

A related suggestion notes that Islamic civilization was more pluralistic at its outset and that science declined as the Islamic world became culturally more homogeneous. In many conquered areas religious believers were initially in the minority. Islam began as a colonial power, and especially at the edges of the Islamic imperium multicultural societies flourished at the outset, mingling diverse cultures and religions—Persian, Indian, Arab, African, Greek, Chinese, Jewish, and Christian. As time went on, conversions increased, and Islam became religiously more rigid and culturally less heterogeneous. Not until the fourteenth century was Islamicization fully complete in many areas. Consequently, the cultural "space" for creative scientific thinkers narrowed and so, again, the scientific vitality of Islam weakened commensurately. However, this account flies in the face of the fact that in its heyday Islamic science often flourished in the most Islamicized centers, such as Baghdad.

War and sociocultural disruptions occasioned by war have likewise been invoked as factors in the decline of Islamic science. In Spain the Islamic world began to be pressured by Christian Europe in the eleventh century, with Toledo falling in 1085, Seville in 1248, and the *reconquista* completed in 1492. In the East, Mongol armies from the steppes of Asia attacked the Islamic caliphate, invading and capturing Baghdad in 1258. Mongol invaders led by Timur (Tamerlane) returned to the Middle East at the turn of the fifteenth century, destroying Damascus in 1402. Although Islamic culture and institutions in the East quickly rebounded from these invasions, the overall effect, or so it is claimed, reinforced religious conservatism and disrupted the conditions necessary for the pursuit of science.

Other experts have focused on the economic decline of Islamic civilization after 1492 as a contributing factor in the cultural decline of its science. That is, once European seafaring traders penetrated the Indian Ocean in 1497, the Islamic world lost its monopoly on the valuable East Asian spice and commodity markets. In such shrinking economic circumstances, the argument suggests that science could hardly have been expected to flourish, especially since it leaned heavily on government support.

Each of these interpretations doubtless possesses some truth, and further historical research will shed more light on understanding the decline of Islamic science. But commentators have also wanted to explain not the decline of Islamic science but the very different question of why modern science did not emerge within the context of Islamic civilization. The question often posed is why, given the advanced state of Islamic science, no Scientific Revolution developed within Islam—why did Islamic scientists not repudiate the earth-centered cosmology of antiquity, expound modern heliocentrism, and develop inertial, Newtonian physics to account for motion in the heavens and on Earth? Much intellectual energy has been expended in dealing with the Islamic "failure" to make the leap to modern science. But to undertake to explain in retrospect the absolute myriad of things that *did not* happen in history confounds the enterprise of historians, who have a difficult enough time rendering plausible accounts for what *did* happen. As evident in this chapter, Islamic science flourished for several centuries, securely assimilated in observatories, libraries, madrasas, mosques, hospitals, and ruling courts. That was its positive achievement. Islamic scientists all labored within the pale of Islam, and they continued to do so for several centuries following the peak of Islamic scientific achievement. To suggest that science somehow "ought" to have developed as it did in the West misreads history and imposes chronologically and culturally alien standards on a vibrant medieval civilization.

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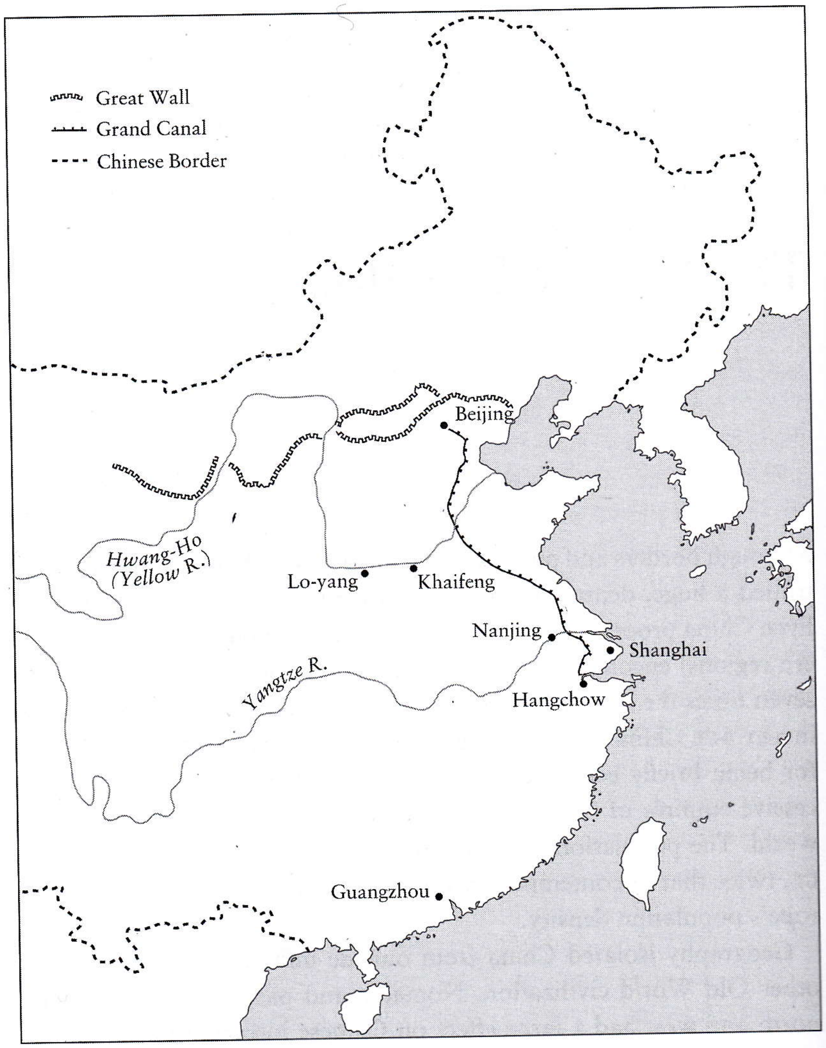
CHAPTER 7

The Middle Kingdom

Although borders and political units fluctuated, Chinese emperors controlled a huge, densely populated territory about the size of Europe. Even China proper (excluding Manchuria, Mongolia, Tibet, and western regions) encompassed about half the area of Europe and was still seven times the size of France (see map 7.1). From its first unification in 221 BCE China was the world's most populous country, and except for being briefly eclipsed by the patchwork Roman Empire, the successive empires of China stood as the largest political entities in the world. The population of China proper reached 115 million in 1200 CE, twice that of contemporary Europe and with nearly five times Europe's population density.

Geography isolated China from outside influences more than any other Old World civilization. Nomadic and pastoral peoples to the north and west had a large effect on Chinese history, to be sure, but mountains, deserts, and inhospitable steppe ringed China on the southwest, west, and north, and impeded contact with cultural and historical developments in West Asia and Europe. The earliest Chinese civilization arose in the valley of the Hwang-Ho (the Yellow River), and only later in historical periods did civilization spread to the lower valley and flood plain of the Yangtze River. China represents an archetypal hydraulic civilization whose cultural orientation faced eastward along these and related river and lake systems.

The technology of writing developed independently in China. A complex ideographic type of writing can be seen in the "oracle bone script" in the Shang dynasty (~1600-1046 BCE). It became highly developed with upwards of 5,000 characters by the ninth century BCE, and characters became standardized by the time of China's unification. Hundreds of basic signs could be combined into thousands (indeed, tens of thousands) of different characters. Because of this complexity and because each Chinese written word embodies phonetic and pictographic elements, Chinese writing was (and is) difficult to master. In



Map 7.1. China. Chinese civilization originated along the Hwang-Ho (Yellow) River in the second millennium BCE. Mountains, deserts, and steppe regions in the north and west effectively cut China off from the rest of Asia. The first unification of China occurred in the third century BCE, producing the largest and most populated political entity in the world. The map shows two of the great engineering works of Chinese civilization: the Great Wall and the Grand Canal.

adhering to the ideographic mode, Chinese writing did not simplify phonetically or syllabically as did ancient Egyptian, Sumerian, and Old Babylonian, but that "obstacle" did not impede the long, unbroken tradition of Chinese literacy and the impressive Chinese literary and scientific record from the second millennium BCE.

China embodies thousands of years of cultural continuity, and one cannot adequately trace here the intricate social and political changes observable in China's history as various empires rose and fell (see table 7.1) Nevertheless, the Song dynasties (960–1279 CE) and the "renaissance" accompanying the Song command attention. In many ways the Song period represents the zenith of traditional China. The several centuries of Song rule formed the golden age of Chinese science and technology, and they provide an effective point of contrast with contemporary developments elsewhere in the world.

The flowering of China under the Song resulted from agricultural changes, notably the upsurge of rice cultivation in South China and in the Yangtze basin beginning in the eighth century. Rice paddies produce a higher yield per acre than any other cultivated crop, so the mere introduction of rice inevitably produced significant social and cultural consequences. After 1012 the government introduced and systematically distributed new varieties of early-ripening and winter-ripening rice from Indochina. Some varieties ripened in 60 days, allowing two and even three harvests a year in favored locales. Other varieties required less water, which meant that new lands could be brought under cultivation. The Song made major efforts to extend rice production by reclaiming marshlands and lakesides, by terracing, and by improving irrigation, all under government direction. The new technique of planting out seedling rice plants eliminated the need for fallow, and the introduction of new tools for cultivating rice, such as the rice-field plow and paddle-chain water-lifting devices, likewise improved efficiency and productivity enough to provide increasingly large surpluses.

The consequences proved dramatic. The population of China more than doubled from 50 million in 800 CE to 115 million (one census reports 123 million) in 1200. The center of gravity of Chinese civilization shifted south, with more than twice as many Chinese living in the south than the north by 1080. Urbanization likewise skyrocketed. According to one report, Song dynasty China contained five cities with populations of more than a million, and another estimate puts the urban population at 20 percent of the total, a remarkably high figure for an agrarian society, one not reached in Europe until the nineteenth century. A system of imperial roads and way stations connected and

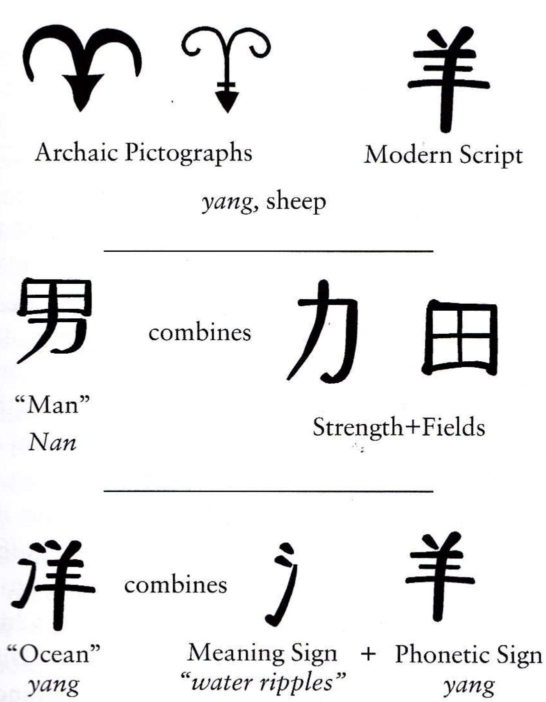


Fig. 7.1. Chinese pictographic writing. Written Chinese languages derive from pictographic antecedents. Various characters can be combined to form new word signs. In some cases parts of characters indicate the sound of the word and/or distinguish the general class of things to which the word in question belongs. Unlike other languages with pictographic origins, written Chinese never simplified into a wholly phonetic or sound-based script, and literacy in China still entails mastery of hundreds of separate word signs. Such difficulties did not prevent the Chinese language from developing sophisticated technical and scientific vocabularies.

Table 7.1
A Chronology of Chinese Dynasties

Early China	
Xia Dynasty	21st–17th centuries BCE
Shang Dynasty	~1600–1046 BCE
Zhou Dynasty	
Western Zhou	1046–771 BCE
Eastern Zhou	770–256 BCE
Warring States Period	475–221 BCE
Early Imperial China	
Qin Dynasty	221–206 BCE
Han Dynasty	206 BCE–220 CE
Three Kingdoms	220–280 CE
Jin Dynasties	265–420
Northern and Southern Dynasties	
Southern Dynasties	420–589
Northern Dynasties	386–581
Classical Imperial China	
Sui Dynasty	581–618
Tang Dynasty	618–907
Five Dynasties	907–960
Liao Dynasty	907–1125
Jin Dynasty	1115–1234
Song Dynasty	
Northern Song	960–1127
Southern Song	1127–1279
Later Imperial China	
Yüan (Mongol) Dynasty	1279–1368
Ming Dynasty	1368–1644
Qing (Manchu) Dynasty	1644–1911
Post-Imperial China	
Republic of China	1912–
People's Republic of China	1949–

organized the vast network. A leisured middle class arose along with the commercialization of agricultural commodities, increased trade, and expanded manufacturing.

Centralization of power in the hands of the emperor and rule by a governing bureaucracy—the mandarinate—reached new heights under the Song. The "mandate of heaven" dictated that the Chinese emperor rule all of China, and an improved civil service to support that mandate proved pervasive in Chinese life. The bureaucracy was huge and monolithic; a later report from Ming times puts the number of state civil servants at 100,000, exclusive of military officers. Such organization allowed direct control by the emperor down to the village level. No intermediary or independent bodies existed in China to challenge the authority of the emperor and the mandarinate. Different traditional provinces and linguistic regions acted as something of brakes to centralizing forces, but no other formal centers of power existed. Towns and cities were neither autonomous nor separate administrative units. Such an exclusive and centralized administration prevented the rise of independent institutional entities, notably colleges or guilds. The omnipresence of the Chinese mandarinate seems also to have restricted any neutral social or intellectual space for science or technology outside of official channels.

The teachings of the Chinese sage Confucius (551–479 BCE) dramatically shaped Chinese high culture, particularly through the official state ideology of Neo-Confucianism elaborated by commentators in Song times. The Confucian outlook focused on the family, humanity, and society, not nature or the world outside of human affairs. Confucianism was a practical philosophy that emphasized the ethical and moral dimensions of behavior and statecraft and the maintenance of a just and harmonious society. Thus, custom, etiquette, virtuous behavior, filial piety, respect for one's elders, submission to authority, the moral example of the sage, and justice (but not law) became the watchwords of Confucianism in Song times. In these ways Confucianism sustained the status quo and the paternalistic and patriarchal society of the day.

The power and appeal of the imperial bureaucracy drained talent that might have flowed into science. The bureaucracy skewed scholarship toward the humanities and the Confucian classics, and it helped enforce a deep divide between learned culture and the crafts. Under the Song, the imperial bureaucracy operated as a true meritocracy open to talent. The state recruited functionaries not through political or hereditary connections, but rather based on ability and performance on exacting state civil-service exams, which provided virtually exclusive access to political power. Already in Han times (206 BCE–220 CE) Chinese officials instituted the system of state examinations, one effect of which was to restrict the political power of the nobility. The Song dynasties reformed the system, and it reached its high point under their rule and continued in effect in China until 1904.

An official board of examiners offered three levels of examination (local, regional, and national) every two to three years. Some unfortunate students devoted their whole lives to taking and retaking the rigorous exams. Passage of even the lowest level exam brought special privileges, such as exemption from the forced labor of the corvée. Passing at the high levels incurred obligations since laureates could not refuse employment in the bureaucracy. Based on a standardized subject matter, the exams focused on Confucian classics, on esoteric literary and humanistic studies, and, under the Song, on administrative problems. Memorization took pride of place, along with recitation, poetry, and calligraphy. With the emphasis on moral learning and the goal of producing a scholar-gentry to rule the country, the civil service exams shaped the values and efforts of the best and brightest Chinese minds for nearly 2,000 years. Certain exceptions aside, science and technology did not figure in the exam system.

Outside the bureaucracy, other elements of society lacked the power and autonomy to be independent sources of any nascent scientific tradition. If the exam system effectively precluded rule by nobles, civilian authority also managed to subordinate military and merchant classes to its power. From the third century BCE China possessed large armies—on the order of a million soldiers. (Song armies numbered 1,259,000 men in 1045.) Yet, the military remained subject to civilian control. Military power was divided, units split up, and overlapping commands established. Merchant activity was likewise tightly controlled so that, unlike in Europe, merchants never rose to social or institutional positions of consequence. From the Confucian point of view, merchant activity, profit, and the accumulation of private wealth were disdained as antisocial vices. Merchants occasionally flourished and achieved great wealth, but periodic prosecutions and confiscations ensured the marginality and low status of merchants as a class in Chinese society. Likewise, the suppression of religious institutions in 842–845 CE, following a period of Buddhist prominence, meant that no clergy could challenge the predominance of the bureaucracy.

The Flowering of Chinese Technology

Learned culture in traditional China was largely separate from technology and the crafts. Calendrical astronomy benefited the state and society, and mathematics played a role in the solution of practical problems, but economic, military, and medical activities were, on the whole, carried out on the strength of traditional techniques that owed nothing to theoretical knowledge or research. Craftsmen were generally illiterate and possessed low social status; they learned practical skills through apprenticeship and experience, and they plied their trades without benefit of scientific theory. Scholars and "scientists," on the other hand, were literate, underwent years of schooling, enjoyed high social status, and remained socially apart from the world of artisans and engineers. The exam system and the bureaucracy, by institutionally segregating scholar-bureaucrats from artisans, craftsmen, and engineers, strengthened the separation of science and technology. The value system of traditional China, like that of Hellenic Greece, looked down upon crass technology. Scholars and literati repudiated working with their hands and preferred more refined concerns such as poetry, calligraphy, music, and belles-lettres.

In considering Chinese technology one must be wary of a tendency to record the priority of the Chinese over other civilizations for this or that invention: the wheelbarrow, the south-pointing chariot, lacquer, gunpowder, porcelain china, the umbrella, the fishing reel, the seed drill, the rotary winnowing fan, the crossbow, suspension bridges, and so on. While such "firsts" are interesting, they are of limited analytical value in historical inquiry. Rather, the starting point for any investigation of Chinese technology must be the realization that the totality of its advanced technologies, regardless of their originality or priority, made China a world leader in technology through the Song era and beyond.

Government control of industries was a characteristic feature of Chinese technology. The government nominally owned all resources in the country, and it monopolized production in key sectors by creating government workshops and state factories for such industries as mining, iron production, salt supply, silk, ceramics, paper-making, and alcoholic beverages. Through these monopolies run by bureaucrats, the Chinese state itself became a merchant producer, in large part to provide for its enormous military needs. The government commanded a vast array of specialized craftsmen, and anyone with technical skills was ostensibly subject to government service. Porcelain manufactories turned out pieces by the millions; bolts of silk issued in like numbers. The Yüan emperors, for example, enlisted 260,000 skilled artisans for their own service; the Ming commanded 27,000 master craftsmen, each with several assistants; and in 1342, 17,000 state-controlled salt workers toiled along the lower Yangtze.

State management of technology and the economy reached a high point in the Song period when more government income came from mercantile activity and commodity taxes than from agricultural levies. One result was the spread of a monied economy. Coinage issuing from government mints jumped from 270,000 strings (of a thousand coins) in 997 to 6 million strings in 1073. As a result of that increase, the Song began issuing paper money in 1024, and paper money became the dominant currency in twelfth- and thirteenth-century China. The technology of paper money is significant not as a world historical "first," but because it facilitated the growth and functioning of Chinese civilization.

Hydraulic engineering represents another basic technology underpinning Chinese civilization. We earlier encountered the essential role of irrigation agriculture in discussing the initial rise of civilization along the Hwang-Ho river in the second millennium BCE. While many canals and embankments existed in China from an early date, the first elements of an empire-wide inland canal system appeared about 70 CE. Engineers completed the nearly 400 miles of the Loyang to Beijing canal in 608 CE and by the twelfth century China possessed some 50,000 kilometers (31,250 miles) of navigable waterways and canals. Completed in 1327, the Grand Canal alone stretched 1100 miles and linked Hangchow in the south with Beijing in the north, the equivalent of a canal from New York to Florida. After the Ming took power they repaired 40,987 reservoirs and launched an incredible reforestation effort in planting a billion trees to prevent soil erosion and to supply naval timber. Of course, such impressive engineering was impossible without the central state to organize construction, to levy taxes, and to redistribute the agricultural surplus. Canals allowed rice to be shipped from agricultural heartlands in the south to the political center in the north. One report has 400,000 tons of grain transported annually in the eleventh century. In Ming times 11,770 ships manned by 120,000 sailors handled inland shipping. Considerable maintenance and dredging were obviously required, all of it carried out by corvée labor, and the neglect of hydraulic systems inevitably led to famine and political unrest.

Pottery was an ancient craft that reached unprecedented artistic heights after the eleventh century. The imperial government owned its own industrial-scale kilns and workshops which came to employ thousands of craftsmen mass-producing both commonplace and luxury items. The Chinese originated porcelain—a mixture of fine clays and minerals fired at a high temperature—at the end of Han times and perfected porcelain wares in the twelfth century. The enduring art and technology of Chinese porcelain represent one of the great cultural achievements of the Song and Ming eras. They bespeak a wealthy and cultivated society, and, indeed, ceramics became a major item of internal and international commerce and of tax income for the state. Chinese pottery made its way through the Islamic world and to Africa. From the Middle Ages onward Europeans came to covet Chinese porcelains, and efforts to duplicate Chinese ceramic technology proved a spur to the pottery industry in Europe at the time of the Industrial Revolution in the eighteenth century.

Textiles constitute another major industry in traditional China. One twelfth-century Song emperor, for example, purchased and received in taxes a total of 1.17 million bolts of silk cloth. The Chinese textile industry is especially notable because of its mechanized character. Sources document the presence of the spinning wheel in China from 1035 CE, and Chinese technologists also created elaborate, water-powered reeling machines to unwind silkworm cocoons and wind silk thread onto bobbins for weaving into cloth. And paper manufacturing, possibly evolving out of the textile industry, provided a product that facilitated the administration of imperial China. Solid evidence exists for paper from late Han times early in the second century CE, although the technology may have originated several centuries earlier.

Chinese bureaucracies depended on writing, literary traditions, and libraries, which already existed in the Shang dynasty in the second millennium BCE. Although paper entered Chinese society at an early date, the technology of taking rubbings from carved inscriptions may have delayed the advent of printing until the first decade of the seventh century. Printing—block printing—at first simply reproduced seals for religious charms. The first book printed by means of whole pages of carved woodblock appeared in 868 CE, and the technology of print-

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ing soon recommended itself to government authorities who used it to print money, official decrees, and handbooks, particularly useful ones in medicine and pharmacy. An official printing office supplied printed copies of the classics to be studied for the civil-service exams, and overall the Chinese government produced an impressive output of printed material in the service of the bureaucracy. The first emperor of the Song dynasty, for example, ordered a compilation of Buddhist scripture, and the work, consisting of 130,000 two-page woodblocks in 5,048 volumes, duly appeared. In 1403 an official Chinese encyclopedia numbered 937 volumes and another of 1609 comprised 22,000 volumes written by 2,000 authors. Printed popular literature also circulated among the elites.

The Chinese invented movable type around 1040, first using ceramic characters. The technology developed further in Korea where the Korean government had 100,000 Chinese characters cast in 1403. But movable type proved impractical compared to woodblock printing, given the style of Chinese writing with pictograms and the consequent need for thousands of different characters. Block printing thus proved not only cheaper and more efficient, but it allowed illustrations, often in many colors. The ability to reproduce pictures put China well ahead of the West in printing technology even after Gutenberg developed movable type in Europe.

Chinese superiority in iron production likewise helps account for the vibrancy of its civilization. Possibly because of limited resources of copper and tin for bronze, Chinese metallurgists early turned to iron. By 117 BCE iron production had become a state enterprise with 48 foundries, each employing thousands of industrial laborers. Production zoomed from 13,500 tons in 806 CE to 125,000 tons in 1078 in the Song period, doubtless because of increased military demands. (By contrast England produced only 68,000 tons of iron in 1788 as the Industrial Revolution got under way in Europe.) Technologically innovative and advanced, the Chinese iron industry used water-powered bellows to provide a blast and smelted the ore with coke (partially combusted coal) by the eleventh century, some 700 years before like processes arose in Europe. By dint of such superior technology Song military arsenals turned out 32,000 suits of armor and 16 million iron arrowheads a year, as well as iron implements for agricultural use.

The invention of gunpowder in mid–ninth-century or early tenth-century China, and, more significantly, the application of gunpowder to military ends beginning in the twelfth century redirected the course of Chinese and world history. Gunpowder seems to have emerged from traditions of Chinese alchemical research and so is a notable historical instance of applied science or a new technology stemming from the world of learning. Its initial use in fireworks was intended not as a military device but as a means to ward off demons. Only as they became threatened by foreign invasion did Song military engineers improve the

Fig. 7.2. Chinese geomancer. Prior to laying out a new city, an expert geomancer or *fêng shui* master consults a compass-like device to ascertain the flow of energy (*chi*) in the locale. He will then use his readings to situate artificial structures in harmony with their natural surroundings.

formula for gunpowder and develop military applications in rockets, explosive grenades, bombs, mortars, and guns.

Unlike paper, the magnetic compass was a technology that Chinese civilization could manage without, but along with gunpowder the case illuminates the few ties between science and technology in traditional China. The mysterious properties of the loadstone—the natural magnetism of the mineral magnetite—were known by 300 BCE and first exploited for use as a fortuneteller's device. Knowledge attained by 100 BCE that a magnetic needle orients itself along a north-south axis was then applied in geomancy or *fêng-shui*, the proper siting of houses,

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temples, tombs, roads, and other installations. An elaborate naturalistic theory later arose to explain the movement of the compass needle in response to energy currents putatively flowing in and around the earth, an example of how, contrary to conventional wisdom today, technology sometimes fosters speculations about nature rather than the reverse.

Sources fail to attest to the use of the compass as a navigational tool at sea until Song times early in the twelfth century. China entered late as a major maritime power, but from the period of the Southern Song through the early Ming dynasties, that is, from the twelfth through the early fifteenth centuries, China developed the largest navy and became the greatest maritime power in the world. Hundreds of ships and thousands of sailors composed the Song navy. Kublai Khan, Mongol founder of the Yüan dynasty, attempted an invasion of Japan in 1281 with a navy of 4,400 ships. The Ming navy in 1420 counted 3,800 ships, of which 1,300 sailed as combat vessels. The Ming launched an official shipbuilding program and constructed 2,100 vessels in government shipyards between 1403 and 1419. With compasses, watertight compartments, up to four decks, four to six masts, and the recent invention of a sternpost rudder, these were the grandest, most seaworthy, technologically sophisticated vessels in the world. The largest approached 300 feet in length and 1,500 tons, or five times the displacement of contemporary European ships. Armed with cannon and carrying up to 1,000 sailors, they were also the most formidable.

The Ming used their powerful navy to assert a Chinese presence in the waters of South Asia and the Indian Ocean. From 1405 to 1433 they launched a series of seven great maritime expeditions led by the Chinese admiral Cheng Ho (also known as Zheng He). With several

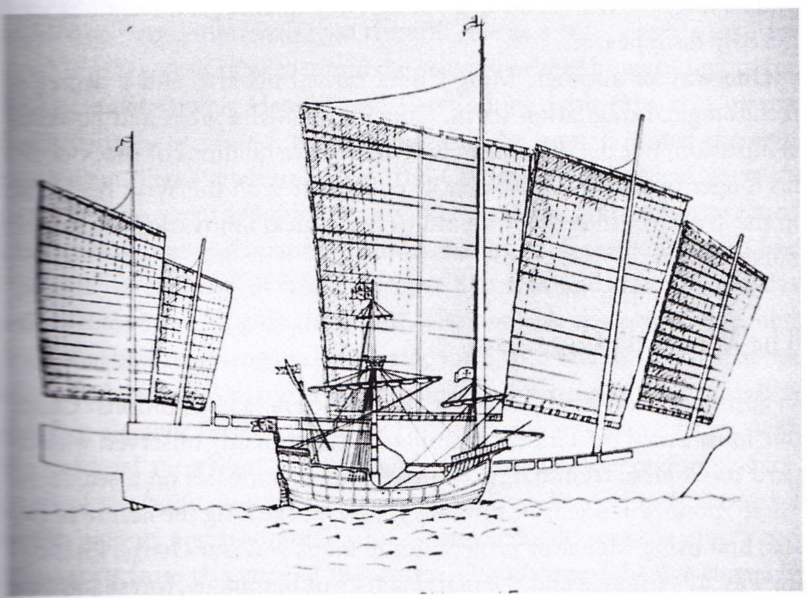


Fig. 7.3. European and Chinese ships. Chinese civilization abandoned maritime exploration and left the Indian Ocean early in the fifteenth century, just decades before European sailors entered the region. The ships of the Chinese admiral Cheng Ho were much larger than European vessels, as shown in this imaginary comparison.

dozen ships and more than 20,000 men on each voyage, Cheng Ho sailed to Vietnam, Thailand, Java, and Sumatra in southeast Asia, to Sri Lanka and India, into the Persian Gulf and the Red Sea (reaching Jedda and Mecca), and down the coast of East Africa, possibly as far as Mozambique. The purpose of these impressive official expeditions seems to have been political, that is, to establish the authority and power of the Ming dynasty, and on at least one occasion Cheng Ho used force to assert his authority. With these initiatives, the Ming acquired a number of vassal states, and at least two Egyptian diplomatic missions wound their way to China.

Then, abruptly, the extraordinary maritime thrust of the Ming came to an end. Official shipbuilding ceased in 1419, and a decree of [illegible] put an end to further Chinese overseas expeditions. No one can say whether the course of world history would have been radically different had the Chinese maintained a presence in the Indian Ocean and rebuffed the Portuguese when they arrived with their puny ships at the end of the same century. Several explanations have been offered to account for the stunning reversal of Chinese policy. One notion suggests that the Chinese repudiated overseas adventures because Cheng Ho was a Muslim and a eunuch, qualities reminiscent of the oppressive Mongol/Yüan years and greatly in disfavor among the nationalistic Ming. Another envisions the expeditions as merely the somewhat idiosyncratic initiative of two Ming emperors, and not as growing organically out of contemporary Chinese society and economy. A strong technical argument has also been advanced. Restoration of the Grand Canal began in 1411–15, and in 1417 the construction of deepwater ("pound") locks on the Grand Canal allowed a year-round link between the Yangtze and Yellow Rivers. Accordingly, the Ming transferred their capital from Nanking in the south to Beijing in the north, and as a result, the need for a strong navy or foreign adventures supposedly disappeared.

One way or another, Ming China turned inward, and a degree of technological stagnation set in. China remained a great and powerful civilization, but the dynamism and innovative qualities of the Song era no longer obtained. Only with its encounter with the West beginning in the seventeenth century would technological innovation once again move China.

The World as Organism

In approaching the subject of the natural sciences in traditional China, one must avoid the tendency, similar to that already observed with regard to Chinese technology, to place undue emphasis on a search for "first" honors in scientific discovery: first recognizing the nature of fossils, first using Mercator projections in maps and star charts, discovering Pascal's triangle and the mathematics of binomials, foreshadowing the even-tempered musical scale, or, particularly far-fetched, crediting alternations of yin and yang as anticipations of the "wave theory" of today's quantum physics. Such claims reflect a perverse judgmentalism and a desire, in the name of multicultural relativism, to inflate the accomplishments of Chinese science while devaluing those of the West. Instead, the present section emphasizes the social history of Chinese science rather than a chronology of discovery, and it strives to show that the relationship between science and society in traditional China parallels the other primary civilizations of the Old World: useful knowledge patronized by the state and developed in support of statecraft and civilization generally.

Any historical evaluation of Chinese science must overcome several further obstacles. The Western concept of science or natural philosophy remained foreign to intellectual thought in traditional China. As one author put it, "China had sciences, but no science." That is, learned experts pursued various scientific activities—in astronomy, astrology, mathematics, meteorology, cartography, seismology, alchemy, medicine, and related studies—but nothing united these separate endeavors into a distinct enterprise of critical inquiry into nature. Indeed, the Chinese language possessed no single word for "science." China, like Egypt and the other bureaucratic civilizations, lacked natural philosophy in the Hellenic sense, and one gathers that Chinese thinkers would have been perplexed by the notion of pure science pursued for its own sake. Chinese society provided no social role for the research scientist, and no separate occupation or distinct profession of science existed. Instead, elite amateurs and polymaths pursued scientific interests, often, perhaps furtively, when employed to gather and apply useful knowledge in a bureaucratic setting.

The traditional Chinese outlook conceived of nature in more holistic and organismic terms than did the West. Already in Han times, a conception emerged that envisaged the universe as a vast, single organism in which the world of nature and the social world of humankind merge in a complete unity. Heaven and Earth along with man and nature harmoniously coexisted, the celestial and the human linked through the person of the emperor. From the Chinese philosophical perspective, the two great complementary forces of yin and yang governed change in nature and in human affairs. In addition, the constituent five "phases" or elements of wood, fire, earth, metal, and water played dynamic roles in making up the world. The outlook was qualitative, and it emphasized recurring cycles, as yin, yang, and one or another of the elemental "phases" assumed predominance over the others. Notably, this five-element (Wuxing) theory further correlates associations with the cardinal directions, climate and the seasons, the major planets, parts of the body, and much more. A medical dimension is thus part of this picture, and traditional Chinese medicine derived diagnoses and treatments from this view of the world. This vision of the five elements

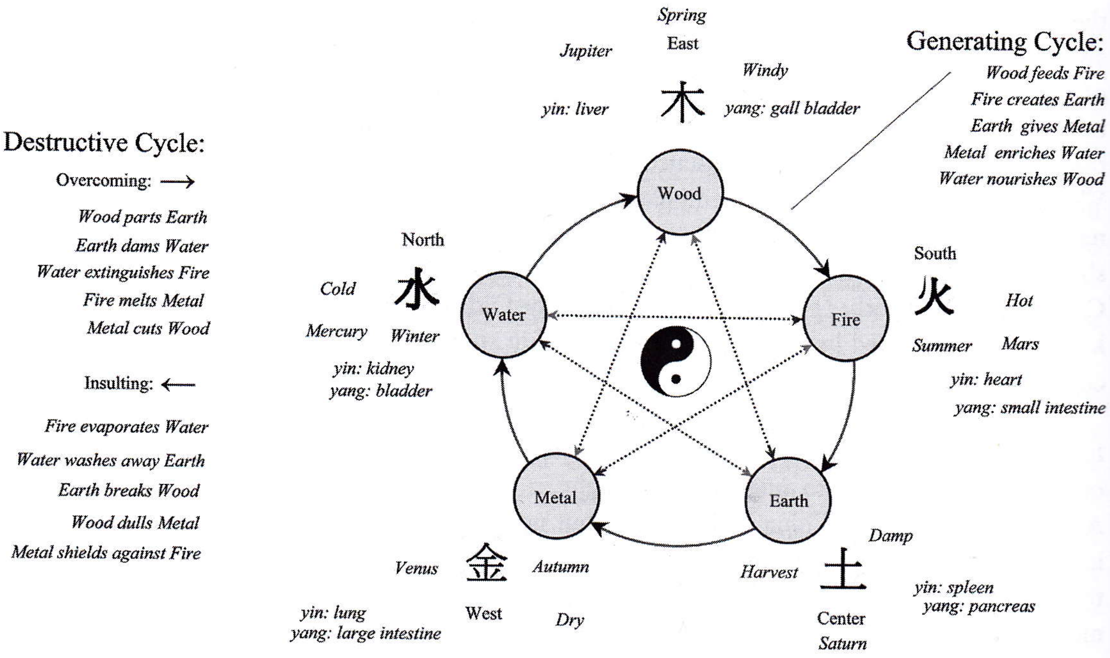
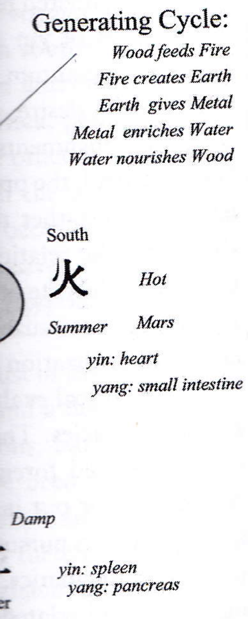


Fig. 7.4. The Five Phases. The traditional Chinese view of the material world and the dynamics of change. Elaborate cycles of yin and yang produce a continually waxing and waning of the elements of wood, fire, earth, metal, and water. These changes further connected to the seasons, to astrology, and to the theory and practice of traditional Chinese medicine.

resembles that of the Aristotelian elements and associated Greek humoral medicine we saw earlier, but it would be a mistake to think of these two highly complex conceptualizations of the nature of nature as in any way the same or causally connected. In considering Chinese scientific thought, then, one must acknowledge that Chinese intellectuals lived in a world separated from the West by more than geography.

On a more mundane level, although schools abounded in China, Chinese educational institutions did not incorporate or provide instruction in the sciences. Founded in the eighth century CE, an Imperial Academy in the capital topped a complex educational structure, with a central Educational Directorate superintending a standardized Confucian curriculum for the empire. A host of private academies following the standard curriculum also blossomed. Unlike European universities, none of these schools possessed a legal charter granting them a permanent, independent existence. All existed by tradition and the will of the emperor. They could be and were closed simply by decree. Furthermore, the entire focus of these schools—public and private alike—was careerist and directed to preparing students to take the state civil-service exams. None granted degrees. Even the Imperial Academy was merely another bureau at which scholarly functionaries taught for limited periods of time, and only one such academy existed in the whole of China, compared to Europe in the following centuries with its scores of autonomous colleges and universities. Although authorities established separate schools of law, medicine, and mathematics around the year 1100 CE, none survived very long. The sciences simply did not figure in Chinese education or educational institutions.



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These cultural and institutional impediments notwithstanding, the necessities of imperial administration dictated that from its inception the Chinese state had to develop bureaucratically useful knowledge and recruit technical experts for its service. In a typical fashion, like writing, applied mathematics became a part of the workings of Chinese civilization. By the fourth century BCE the Chinese developed a decimal place-value number system. Early Chinese mathematics used counting rods and, from the second century BCE, the abacus to facilitate arithmetical calculations. By the third century BCE Chinese mathematicians knew the Pythagorean theorem; they dealt with large numbers using powers of 10; they had mastered arithmetic operations, squares, and cubes, and, like the Babylonians, they handled problems we solve today with quadratic equations. By the thirteenth century CE the Chinese had become the greatest algebraists in the world.

While the record occasionally indicates Chinese mathematicians engaged in the seemingly playful exploration of numbers, as in the case of the calculation of π to 7 decimal places by Zu Chougzhi (429–500 CE), the overwhelming thrust of Chinese mathematics went toward the practical and utilitarian. The first-century CE text, *Nine Chapters on the Mathematical Art* (*Jiu Zhang Suan Shu*), for example, took up 246 problem-solutions dealing with measurements of agricultural fields, cereal exchange rates, and construction and distribution problems. To solve them, Chinese mathematicians used arithmetic and algebraic techniques, including simultaneous "equations" and square and cube roots. Indian influences made themselves felt in Chinese mathematics in the eighth century, as did Islamic mathematics later. Characteristically, Chinese mathematicians never developed a formal geometry, logical proofs, or deductive mathematical systems such as

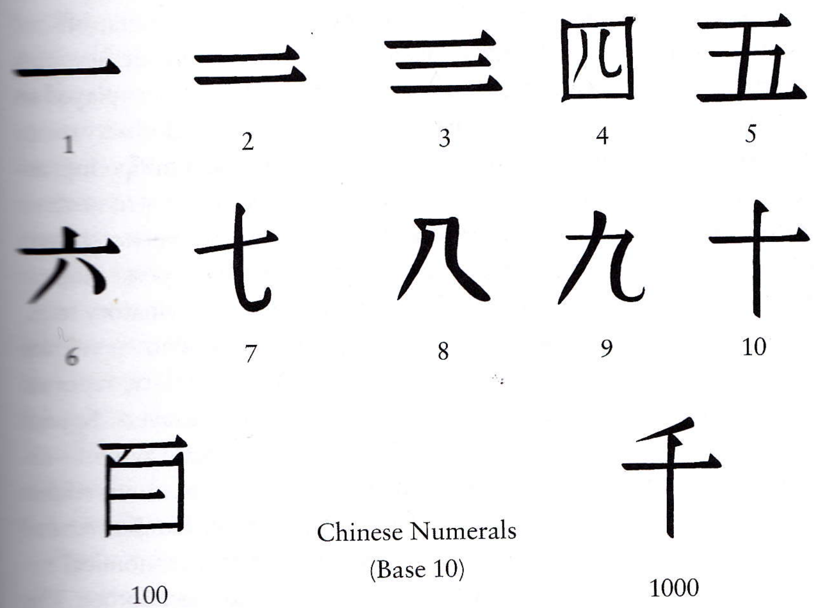

Fig. 7.5. Chinese numerals (base 10). Chinese civilization developed a decimal, place-value number system early in its history. Supplemented with calculating devices such as the abacus, the Chinese number system proved a flexible tool for reckoning the complex accounts of Chinese civilization.

those found in Euclid. The social history of Chinese mathematics reveals no reward system for mathematicians within the context of the bureaucracy. Mathematicians worked mostly as scattered minor officials, their individual expertise squirreled away in separate bureaus. Alternatively, experts wandered about without any institutional affiliation. The three greatest contemporary Song mathematicians (Ts'in Kieou-Chao, Li Ye, and Yang Housi), for example, had their works published, but did not know each other, had different teachers, and used different methods. In considering the character and social role of Chinese mathematics, one must also factor in a strong element of numerology and traditions of mathematical secrets, all of which tended to fragment communities and disrupt intellectual continuity.

A pattern of state support for useful knowledge, characteristic of centralized societies, is nowhere more evident than in Chinese astronomy. Issuing the official calendar was the emperor's exclusive prerogative, a power apparently exercised already in the Xia dynasty (21st to 17th centuries BCE). Like their Mesopotamian counterparts, Chinese calendar-keepers maintained lunar and solar calendars—both highly accurate—and they solved the problem of intercalating an extra lunar month to keep the two in sync like the Babylonians by using the so-called Metonic cycle of 19 years and 235 lunations, that is, twelve years of twelve lunar months and seven years of thirteen lunar months.

Because disharmony in the heavens supposedly indicated disharmony in the emperor's rule, astronomy became a matter of state at an early period and the recipient of official patronage. Professional personnel superintended astronomical observations and the calendar even before the unification of China in 221 BCE, and soon an Imperial Board or Bureau of Astronomy assumed jurisdiction. Astronomical reports to the emperor were state secrets, and because they dealt with omens, portents, and related politico-religious matters, official astronomers occupied a special place in the overall bureaucracy with offices close to the emperor's quarters. Chinese astronomers played so delicate a role that they sometimes altered astronomical observations for political reasons. In an attempt to prevent political tampering, astronomical procedures became so inflexible that no new instruments or innovations in technique were permitted without the express consent of the emperor, and edicts forbade private persons from possessing astronomical instruments or consulting astronomical or divinatory texts.

Marco Polo (1254–1324), the Italian adventurer who served for 17 years as an administrator for the Mongol/Yüan dynasty, reported that the state patronized 5,000 astrologers and soothsayers. Special state exams—given irregularly outside the standard exam system—recruited mathematicians and astronomers for technical positions within the bureaucracy. Unlike the rest of the bureaucracy, families tended to monopolize positions requiring mathematical and astronomical expertise, with jobs handed down from one generation to another. The rules prohibited children of astronomers from pursuing other careers and, once appointed to the Astronomical Bureau, individuals could not transfer to other agencies of government.

The Chinese developed several theories of the cosmos, including one wherein the celestial bodies float in infinite empty space blown by a "hard wind." From the sixth century CE the official cosmology consisted of a stationary earth at the center of a great celestial sphere. Divided into twenty-eight "lunar mansions" corresponding to the daily progress of the moon in its monthly passage through the heavens, this sphere turned on a grand axis through the poles and linked heaven and earth. The emperor, the "son of heaven," stood as the linchpin of this cosmology, while China itself rested as the "middle kingdom" among the four cardinal points of the compass.

Although weak in astronomical theory, given the charge to search for heavenly omens, Chinese astronomers became acute observers. With reliable reports dating from the eighth century BCE and possibly from the Shang dynasty several centuries earlier, the range of Chinese observational accomplishments is impressive. The richness of documentary material reveals that, already in the fourth century BCE, Chinese astronomers measured the length of the solar year as 365¼ days. The north star and the circumpolar stars that were always visible in the night sky received special attention from Chinese astronomers who produced systematic star charts and catalogues. Chinese astronomers recorded 1,600 observations of solar and lunar eclipses from 720 BCE, and developed a limited ability to predict eclipses. They registered seventy-five novas and supernovas (or "guest" stars) between 352 BCE and 1604 CE, including the exploding star of 1054 (now the Crab Nebula), visible even in the daytime but apparently not noticed by Islamic or European astronomers. With comets a portent of disaster, Chinese astronomers carefully logged twenty-two centuries of cometary observations from 613 BCE to 1621 CE, including the viewing of Halley's comet every 76 years from 240 BCE. Observations of sunspots (observed through dust storms) date from 28 BCE. Chinese astronomers knew the 26,000-year cycle of the precession of the equinoxes. Like the astronomers of the other Eastern civilizations, but unlike the Greeks, they did not develop explanatory models for planetary motion. They mastered planetary periods without speculating about orbits.

Government officials also systematically collected weather data, the earliest records dating from 1216 BCE; to anticipate repairs on hydraulic installations, they gathered meteorological data on rain, wind, snowfalls, the aurora borealis ("northern lights"), and meteor showers. They also studied the composition of meteorites and compiled tide tables beginning in the ninth century CE. The social utility of this research is self-evident.

Three waves of foreign influences impacted on Chinese science. The first wave broke in the years 600–750 CE, coincident with Buddhist and Indian influences in T'ang times. Chinese Buddhists undertook pilgrimages to India from the early fifth century CE in search of holy texts. A significant translation movement developed, wherein over time nearly 200 teams of translators rendered some 1,700 Sanskrit texts into Chinese. As part of this movement, the secular sciences of India, including works in mathematics, astrology, astronomy, and medicine, made their way to China.

A second wave of foreign influence (this time Islamic) had a strong impact beginning with the Mongol conquest of China by Kublai Khan in the thirteenth century. Although not Muslims themselves, Mongol rulers employed Islamic astronomers in the Astronomical Bureau in Beijing and even created a parallel Muslim Bureau of Astronomy alongside the one for traditional Chinese astronomy; and later Ming emperors continued the tradition of a parallel Muslim Astronomical Bureau. Muslim astronomers deployed improved astronomical instruments, including a 40-foot-high gnomon, sighting tubes, and armillary spheres and rings adjusted for the Chinese (and not Western) orientation to the north celestial pole. Across the greater Mongol imperium, reciprocal Chinese-Persian contact developed in Yüan (Mongol) times (1264–1368) that included Chinese contact with Islamic astronomers at the Maraghah observatory. This tie put Chinese astronomers in touch with the works of Euclid and Ptolemy, but, consistent with their indifference to abstract science, the Chinese did not translate or assimilate these pillars of Western science before the third wave and the arrival of Europeans in the seventeenth century.

Before and after the Mongols, the Chinese used complex astronomical clocks and planetaria known as orreries. About 725 CE a Chinese artisan-engineer, Liang Ling-Tsan, invented the mechanical escapement, the key regulating device in all mechanical clocks. Using the escapement, a small tradition of clock and planetarium construction thereafter unfolded in China. This tradition reached its height at the end of the eleventh century when Su Sung (1020–1101), a Song dynasty diplomat and civil servant, received a government commission to build a machine that would replicate celestial movements and correct embarrassing shortcomings in the official calendar then in use. The Jurchen Tartars moved Su Sung's tower in 1129 after they captured Kaifeng from the Song. Finally, lightning struck it in 1195, and some years later, for want of skilled mechanics, Su Sung's great machine fell into complete disrepair. With it, Chinese expertise in mechanical horology declined, to the point where officials expressed amazement at Western clocks when they came to China in the seventeenth century. Su Sung's clock and like instruments did not seriously affect traditional practices within the Chinese Astronomical Bureau, but the case represents another historical example, not of technology derived from abstract knowledge of nature, but, quite the converse, of an independent technology applied in the service of science and scientific research.

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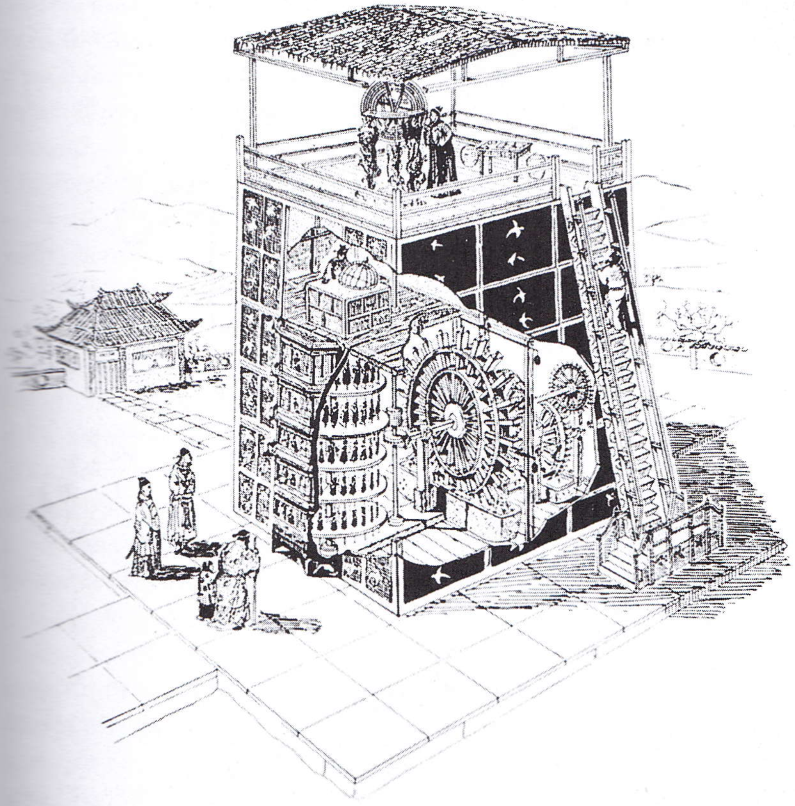


Fig. 7.6. Su Sung's astronomical clock. Built in 1090 Su Sung's clock was an impressive feat of mechanical engineering and the most complex piece of clockwork to that point in history. Housed within a 40-foot-high tower, powered by a waterwheel, and controlled by complicated gearing, Su Sung's machine counted out the hours and turned a bronze armillary sphere and a celestial globe in synchrony with the heavens.

Earthquakes seriously affected China—800,000 people are reported to have died in a catastrophic earthquake in 1303, for example. Because it fell to the government to provide relief to outlying areas, the study of earthquakes became a practical matter of state. Earthquake records date from 780 BCE, and from Han times state astronomers of the Astronomical Bureau had the duty of recording them. Pursuant to that charge, in the second century CE Chang Heng created the remarkable "earthquake weathercock," an ingenious seismograph or earthquake detector. Many such machines existed in traditional China, and later in Mongol times they passed to Islam and the Maraghah observatory.

Cartography or map-making became yet another notable dimension of Chinese scientific expertise developed and deployed in the service of state administration. Chinese map-makers created highly accurate maps of the Chinese empire using various grid systems including what became known in the West as Mercator projections with unequal spacing of latitudes. They also produced relief maps, and in 1027 under the Northern Song they designed a wagon for measuring distances overland, and Ming cartographers produced several atlases after Cheng Ho's maritime expeditions into the Indian Ocean.

As befitted a highly centralized society, medicine was strictly regulated by the state and the practice of medicine was considered a form

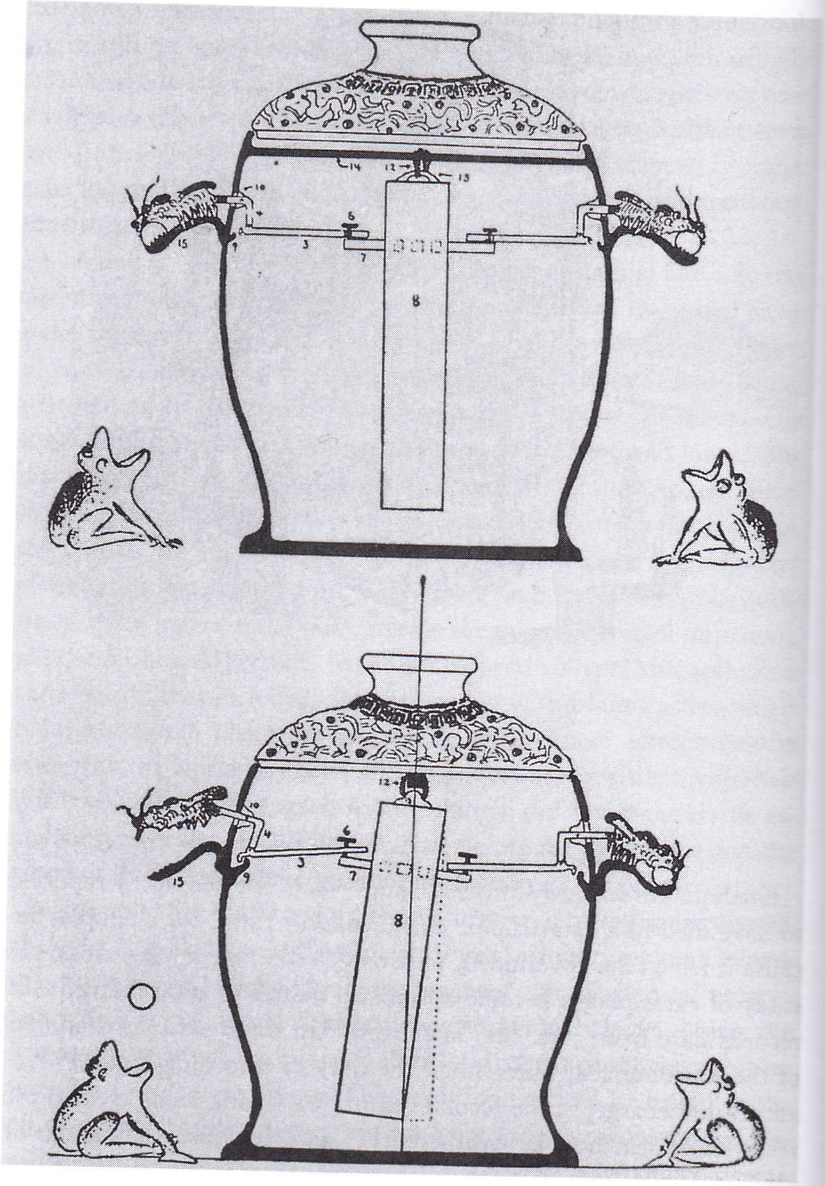
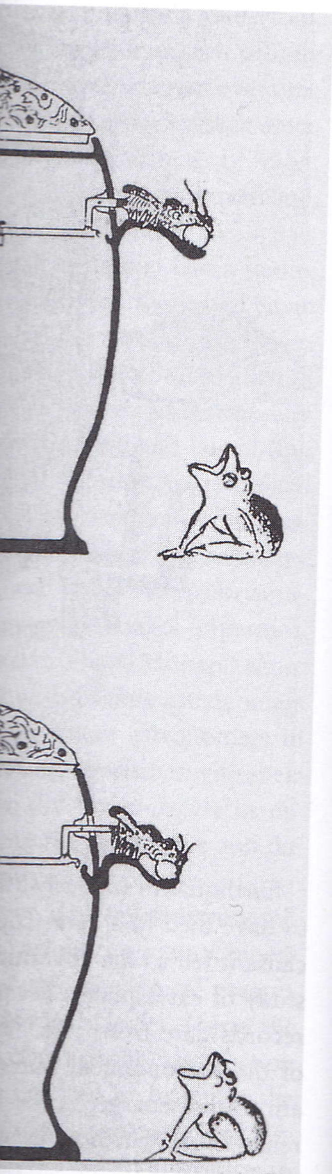


Fig. 7.7. Chinese seismograph. Earthquakes regularly affected China, and the centralized state was responsible for providing relief for earthquake damage. As early as the second century BCE, Chinese experts developed the device depicted here. An earthquake would jostle a suspended weight inside a large bronze jar, releasing one of a number of balls and indicating the direction of the quake.

of public service. An Imperial Medical College came into existence in T'ang times (seventh to the tenth century CE), and physicians had to pass strict examinations. Court physicians occupied well-paid positions, and medical, like astronomical, expertise ran in families. Hospitals, or at least hospice-like organizations, arose in China out of Buddhist and Taoist philanthropic initiative, but these became state institutions after the suppression of religious foundations in 845 CE. To guide physicians, the central government issued many official textbooks dealing with general medicine, pharmacy, pediatrics, legal medicine, gynecology, and like subjects. One Song pharmaceutical document dating from around 990 CE contained 16,835 different medical recipes. The numerous botanical and zoological encyclopedias also



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deserve note, in part for their medicinal advice; a government official, Li Shih-Chen, compiled the *Pen Tsao Kang Mu*, or *Classification of Roots and Herbs*, which listed 1,892 medicaments in fifty-two volumes. Illustrations graced many of these books. The fact that works of natural history seem to take a special interest in insects, notably the silkworm, or that artificial breeding programs for the silkworm began early in Chinese history make plain once more that the state exploited useful knowledge across a wide range of applications.

Finally along these lines, one must not overlook magic, alchemy, and the occult sciences in traditional China. An element of the magical and the divinatory ran through Chinese medicine, astronomy, geography, and mathematics, the latter especially concerned with propitious numbers. Chinese alchemy became the most developed branch of esoteric knowledge, closely associated with Taoist religious philosophy. Popular from Han times, alchemy in the East, as in the West, was a practical science concerned with making elixirs of immortality and transmuting base metals into silver and gold, but Chinese adepts engaged in these efforts less for crass monetary benefit than from contemplative, spiritual motivations and the goal of spiritual transcendence. In some instances at least, alchemy attracted official patronage, as in the case of the Northern Wei emperor who supported an alchemical laboratory from 389 to 404 CE. Alchemists sought to duplicate natural processes carried on within the earth. They built elaborate furnaces and followed intricate alchemical procedures, and, as we saw, gunpowder emerged as an inadvertent by-product of alchemical experimentation.

As in so much else in Chinese history, a certain rigidity and decline began to affect Chinese science, medicine, and technology during the Ming dynasty in the fourteenth and fifteenth centuries CE. The reasons may well have been political. Unlike the expansive and innovative Song or the internationally open Mongols, Ming China turned inward and developed isolationist, conservative policies. Two centuries after the apogee of Chinese algebra under the Song, for example, Chinese mathematicians could no longer fathom earlier texts. A century after the great clockmaker Su Sung died, to repeat an example, no one could repair, much less duplicate, his handiwork. By the time Europeans arrived in China at the turn of the seventeenth century, the stagnation from the glory days of the Song had taken its toll for several centuries.

The third wave of foreign influence impacting on Chinese science emanated from Western Europe. The Jesuit scientist and missionary Matteo Ricci (1552–1610) arrived in Macao on the Chinese coast in 1582 and finally gained admission to Beijing in 1601. The Ming emperor, the court, and Chinese society generally remained hostile to Ricci's religion and his efforts to win converts, but they took special interest in what he could communicate of Western mathematics, astronomy, the calendar, hydraulics, painting, maps, clocks, and artillery, and the ability he brought to translate Western technical treatises into

Chinese. Indeed, Ricci himself became a court astronomer and mathematician and the titular deity of Chinese clockmakers. With Ricci leading the way, the Jesuits succeeded in their mission in China primarily because of their greater calendrical and astronomical expertise. In fact, the emperor handed over operational control of the Astronomical Bureau to the Jesuits. Ironically, Ricci brought with him not the new heliocentric astronomy of Copernicus, Kepler, and Galileo but, instead, perfected forms of Ptolemaic astronomy that Europeans had derived from Islamic sources and antiquity. In other words, the European science Ricci brought to China cannot be retrospectively praised because it was more "correct" than contemporary Chinese science. Rather, his Chinese hosts and employers valued it by the only measure that counted, its superior accuracy and utility in a Chinese context.

With the arrival of Ricci in China the subsequent history of Chinese science largely becomes its integration into ecumenical, world science.

Illicit Questions

As the diversity and sophistication of Chinese scientific traditions have become more evident to scholars over the last decades, a fundamental explanatory question has emerged: why the Scientific Revolution did not occur in China. As detailed in part 3, the umbrella term "Scientific Revolution" refers to the historical elaboration of modern science and the modern scientific worldview in Europe in the sixteenth and seventeenth centuries: the shift to a sun-centered planetary system, the articulation of a universal principle to explain celestial and terrestrial motion, the development of new approaches to the creation of scientific knowledge, and the institutionalization of science in distinct institutions. Since medieval China was scientifically and technologically more developed than Europe in many fields, it does indeed seem surprising that the Scientific Revolution unfolded in Europe and not in China. Over and over again, therefore, the question has arisen of what "went wrong" in China, what "handicapped" Chinese science, or what "prevented" the Scientific Revolution from happening there.

Historians to date have introduced several different explanations of why the Scientific Revolution failed to occur in China, but they all miss the point that science and learning were seamlessly integrated into the fabric of contemporary Chinese society and culture. They miss the point, too, that the historian's job is to explain what happened and not what didn't happen.

Regardless, the complexities of written and spoken Chinese may have made it less than an ideal medium for expressing or communicating science. That is, because mandarin Chinese and related languages are monosyllabic and written in pictographs, they are ambiguous and ill-suited as precise technical languages for science. But other experts

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dispute this suggestion, pointing to exact technical vocabularies in Chinese.

Chinese "modes of thought" may have proved inimical to logical, objective scientific reasoning of the sort that developed in the West. Historians have identified a persistent cultural pattern in China variously labeled as analogical reasoning or as correlative or "associative" thinking. This style of thinking, it is said, strove to interpret the world in terms of analogies and metaphorical systems of paired correspondences between diverse things (such as virtues, colors, directions, musical tones, numbers, organs, and planets) based on the fundamental forces of yin and yang and the five "phases" of metal, wood, water, fire, and earth. Yin and yang thus parallel female and male, day and night, wet and dry, the emperor and the heavens; "wood" becomes associated with "spring" and the cardinal direction "east," and so on. In a related way, the famous divinatory work, the "Book of Changes," the *I Ching*, purportedly exercised a negative influence on Chinese thought in that it rigidly defined analytical categories and unduly dominated the attention of Chinese intellectuals by promoting analogical reasoning.

Commentators have also blamed the related lack of a scientific method in China for the stagnant quality of Chinese science. They point to the suppression of two early schools of thought in China, the Mohists and the Legalists, whose tenets resembled Western scientific approaches and whose methods conceivably could have engendered Western-style science and a Scientific Revolution in China. The Mohist school, derived from the thought of Mo-Ti (fifth century BCE), primarily dealt with political matters, but its followers, together with a related group known as the Logicians, emphasized logic, empiricism, and deduction and induction as means of knowing, and thus conceivably could have given rise to a scientific tradition akin to what developed in the West. Gaining prominence in the fourth and third centuries BCE, the other school of thought, the Legalists, sought to develop a universal law code. Their efforts at classification and quantification, had they succeeded politically, might also have established a basis for the rise of modern science in China. The harsh approach of the Legalists won them little favor, however, and with the advent of the Han dynasty in 206 BCE both they and the Mohist school found themselves repudiated and replaced by the more mainstream but less strictly scientific philosophies of Taoism and Confucianism.

Traditional Chinese thought also lacked a concept of "laws of nature." Unlike Islam or the Christian West, Chinese civilization did not entertain notions of a divine, omnipotent lawgiver who issued fixed commandments for humans and for nature. Especially after the failure of the Legalists, Chinese society by and large was not subject to strictly defined positive law and law codes; the more flexible concepts of justice and custom generally governed Chinese legal proceedings. As a result, it made no sense for Chinese intellectuals to inquire into laws of nature or to find motivation for scientific efforts to discover order in God's handiwork.

Another notion advanced to explain the so-called failure of Chinese science concerns the felt cultural superiority of the Chinese. That is, China was a great and ancient civilization, culturally homogeneous, inward-looking, with a long written tradition and with a strong emphasis on traditional wisdom. China thus had no reason to overturn its traditional view of the world or to investigate or assimilate scientific knowledge of "barbarians" outside of China.

The dominant philosophies of Confucianism and Taoism likewise have been censured for stultifying scientific inquiries in traditional China. Several features of the Confucian outlook did indeed prove antithetical to the pursuit of science in the Western manner: the focus on society and human relations (and not a separate "nature"), the disdain of the practical arts, and the repudiation of "artificial" acts (i.e., experiment). Based on the Tao—"the way"—and the idea of universal harmony through cooperation, the Taoist outlook dictated that followers take no action in conflict with or contrary to nature. The very idea of any special inquiry into an "objective" nature, much less a prying, experimental prodding of nature, was foreign to Taoism. From these points of view, the Western conception of nature and scientific inquiry remained alien to the Chinese experience.

A final proposal suggests that because the merchant classes remained largely peripheral to Chinese civilization, modern science could not emerge in traditional China. Had entrepreneurs and free-market capitalism been encouraged in China and not subordinated to monolithic bureaucratic control, then, this argument suggests, perhaps more of a free market of ideas might have evolved, independent institutions akin to the university might have developed, and modern science conceivably resulted.

Each of the preceding explanations of why the Scientific Revolution did not unfold in China doubtless reflects some insight into circumstances in China before the coming of Europeans. However, akin to the previously encountered case of Islamic science, it is crucial to repeat that the negative question of why the Scientific Revolution did not occur in China is foreign to the historical enterprise and not one subject to historical analysis. The number of such negative questions is, of course, infinite. This particular question retrospectively and fallaciously presupposes that somehow China *should* have produced the Scientific Revolution and was only *prevented* from doing so because of obstacles or because China lacked some elusive necessary condition. It is a gross mistake to judge Chinese science by European standards, and only a retrospective projection of later European history onto the history of Chinese science would demand that China necessarily could and should have taken the same path as Europe. Quite the contrary, despite its comparative limitations, science in traditional China functioned perfectly well within its own bureaucratic, state, and social contexts. Such is not a moral judgment of the high and ancient civilization of China, just good history.

The question thus remains why the Scientific Revolution unfolded in Europe rather than why it did not happen elsewhere. Perhaps it is not too early to suggest that in an ecological context where government support but also government control was less pervasive, individual thinkers had more space and freedom to apply critical faculties to abstract questions.