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 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 adhering

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.

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 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.

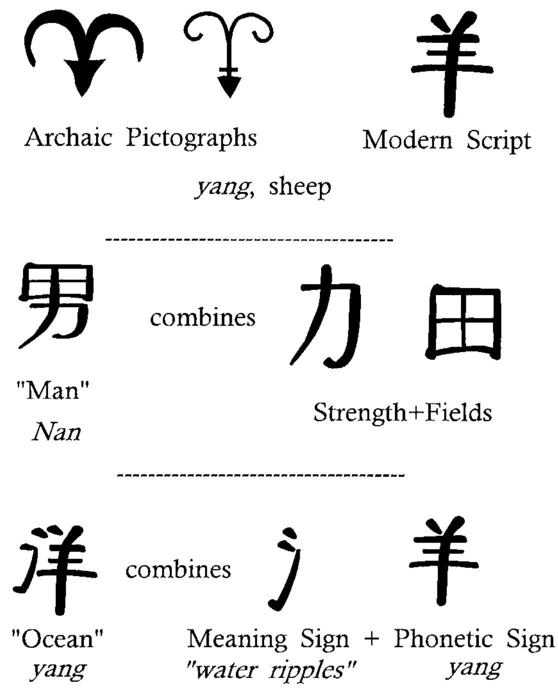

Fig. 7.1. Chinese pictographic writing. Written Chinese languages derive from pictographic antecedents. Various characters can be combined to form new word signs. In some cases parts of characters indicate the sound of the word and/or distinguish the general class of things to which the word in question 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.

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

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–

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, 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. 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 printing 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.

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 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 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 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 get along without, but 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, 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 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 1433 put an end to further Chinese overseas expeditions. No one can say

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.

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 or-

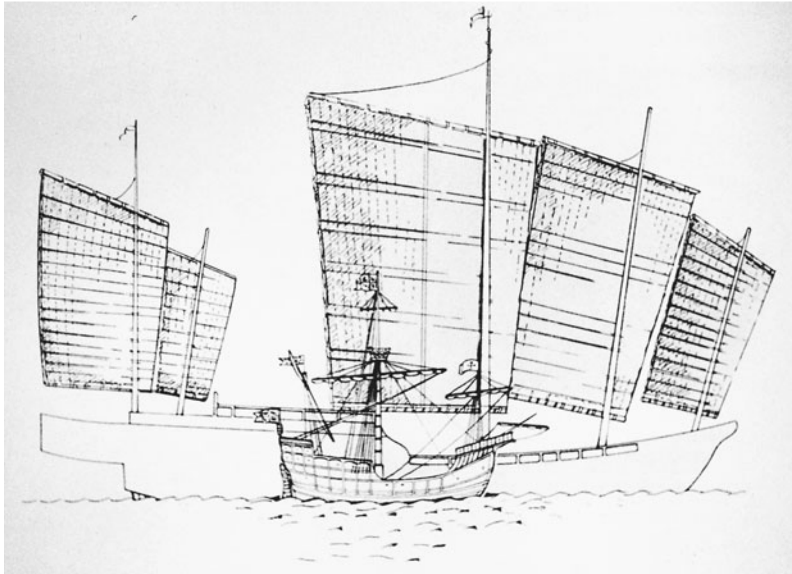

Fig. 7.3. European and Chinese ships. Chinese civilization abandoned maritime exploration and left the Indian Ocean early in the fifteenth century, just decades before European sailors entered the region. The ships of the Chinese admiral Cheng Ho were much larger than European vessels, as shown in this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

ganically 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" of metal, wood, water, fire, and earth 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. 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.

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 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 Yüan (Mongol) 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

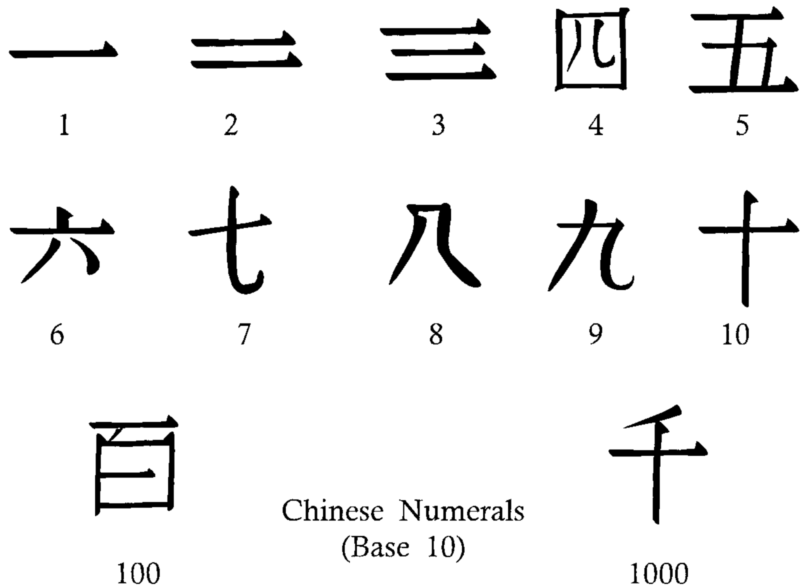

Fig. 7.4. Chinese numerals (base 10). Chinese civilization developed a decimal, place-value number system early in its history. Supplemented with calculating devices such as the abacus, the Chinese number system proved a flexible tool for reckoning the complex accounts of Chinese civilization.

"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, 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 Tang 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 escapment, 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.

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 of public service. An Imperial Medical College came into existence in Tang times (seventh to tenth centuries CE), and physicians had to pass strict examinations. Court physicians occupied well-paid positions, and medical expertise, like astronomical, 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

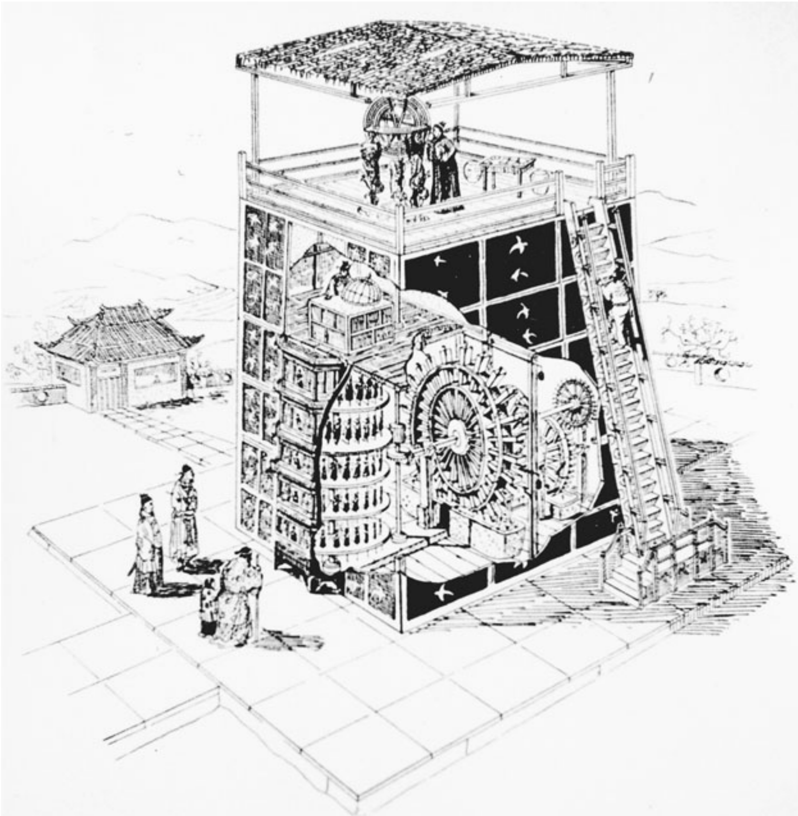

Fig. 7.5. Su Sung's astronomical clock. Built in 1090 Su Sung's clock was an impressive feat of mechanical engineering and the most complex piece of clockwork to that point in history. Housed within a 40-foot-high tower, powered by a waterwheel, and controlled by complicated gearing, Su Sung's machine counted out the hours and turned a bronze armillary sphere and a celestial globe in synchrony with the heavens.

botanical and zoological encyclopedias also 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

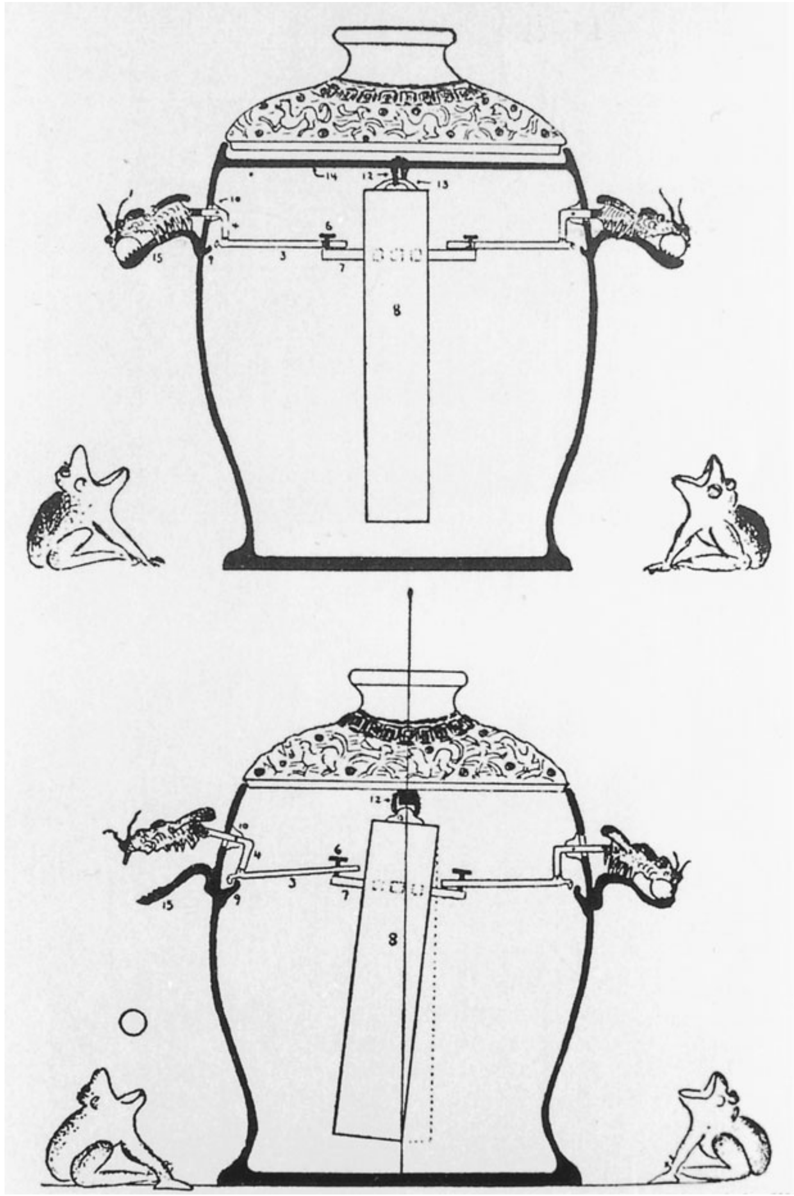

Fig. 7.6. Chinese seismograph. Earthquakes regularly affected China, and the centralized state was responsible for providing relief for earthquake damage. As early as the second century BCE, Chinese experts developed the device depicted here. An earthquake would jostle a suspended weight inside a large bronze jar, releasing one of a number of balls and indicating the direction of the quake.

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 arises 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. 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 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 "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 and state context. 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.