Heritage of China:

□

Contemporary Perspectives on Chinese Civilization

EDITED BY
Paul S. Ropp

CONTRIBUTORS
T. H. Barrett · Jack L. Dull · Patricia Ebrey
Albert Feuerwerker · David N. Keightley · Stephen Owen
Paul S. Ropp · William T. Rowe · Nathan Sivin
Jonathan Spence · Michael Sullivan · Tu Wei-ming
Karen Turner

1990

UNIVERSITY OF CALIFORNIA PRESS
Berkeley Los Angeles Oxford

SEVEN

□

Science and Medicine in Chinese History

Nathan Sivin

The historical discoveries of the last generation have left no basis for the old myths that the ancestry of modern science is exclusively European and that before modern times no other civilization was able to do science except under European influence. We have gradually come to understand that scientific traditions differing from the European tradition in fundamental respects—from techniques, to institutional settings, to views of nature and man's relation to it—existed in the Islamic world, India, and China, and in smaller civilizations as well. It has become clear that these traditions and the tradition of the Occident, far from being separate streams, have interacted more or less continuously from their beginnings until they were replaced by local versions of the modern science that they have all helped to form.

Central to this clearing of the air has been the study of China. There the record of technical endeavor has been fullest, most continuous, most accessible, and most exactly dated. That is only what one would expect of a state that was administered by a full-fledged bureaucracy two thousand years ago and a country where books were being routinely printed four hundred years before the Gutenberg Bible.

Understanding the technical traditions of other cultures is not just a matter for exotic tastes. To the contrary, this wider awareness has transformed our sense of Europe's development. Consider, for example, Francis Bacon's influential attempt, shortly after 1600, to explain that great efflorescence of human knowledge and activity that we now call the Renaissance:

This chapter is a revision of "Science in China's Past," in *Science in Contemporary China*, ed. Leo Orleans (Stanford: Stanford University Press, 1980), 1–29.

> Again, it is well to observe the force and virtue and consequences of discoveries, and these are to be seen nowhere more conspicuously than in those three which were unknown to the ancients, and of which the origin, though recent, is obscure and inglorious; namely, printing, gunpowder, and the magnet. For these three have changed the whole face and state of things throughout the world; the first in literature, the second in warfare, the third in navigation; whence have followed innumerable changes, insomuch that no empire, no sect, no star seems to have exerted greater power and influence in human affairs than these mechanical discoveries.[1]

Bacon's understanding was still conventional in 1920, although by then the attention of historians had largely shifted back from inventions to politics and religion ("empires" and "sects") if not to astrology ("stars").

Today the origins of Bacon's three inventions are a great deal less obscure. None of the three was in fact a European discovery. Printing I have already mentioned. Movable clay type was used to mold inscriptions in Chinese cast bronze vessels of the mid second millennium B.C. The earliest extant texts printed on paper from carved wood blocks originated in Korea by 751 and in Japan about 770 (nearly one thousand years after the Chinese invention of paper and four hundred years before its introduction to Europe).

Because printers needed thousands of different characters, labor was cheap, and books were published in a series of small printings, printing with movable type developed slowly and did not replace the older process until the twentieth century. We have an account of Chinese ceramic movable-type printing in the 1040s. The oldest such book that still exists (set in wood type) dates from the 1350s. It is not in Chinese but in the Tangut script of the northwest frontier. Metal type was in use still earlier. Printing with it was brought to a high state of perfection in Korea through a succession of royally subsidized experiments that culminated in the early fifteenth century.

As printing evolved across East Asia, its potentialities for changing "the face and state" of literature were by no means unexplored. By 1100, for instance, the Chinese government had authorized the printing of standard collections of texts in an attempt—often repeated but always with limited success—to control education. This was the case not only in the humanistic classics but also in such fields as mathematics and medicine.

As for gunpowder, formulas for flare mixtures appear in Chinese alchemical books of the ninth century A.D. or a little earlier. The propor-

1. Francis Bacon, *The New Organon and Related Writings*, Library of Liberal Arts, no. 97 (New York: Liberal Arts Press, 1960), 118. Joseph Needham, *The Grand Titration: Science and Society in East and West* (Toronto: University of Toronto Press, 1969), 62–76, has several interesting observations on this passage.

tions that make gunpowder explosive were known by 1050, and up-to-date commanders over the next two centuries had at their disposal increasingly destructive flamethrowing devices, bombs hurled by trebuchets, and rocket weapons. Between 1270 and 1320 metal-barreled cannon appeared on the Mongols' main battlefronts in Europe, the Islamic west, and China. Although it is not beyond doubt that the inventions that constitute the cannon were finally assembled in Cathay, the prehistory of the crucial propellant and of weapons that used it to fire projectiles was clearly Chinese.

Magnetic attraction was not a matter of recent knowledge in Bacon's time. It is clear that he was speaking of its use in the navigational compass, for the polarity and directive property of lodestone were known and applied to steering by Europeans late in the twelfth century. In China it is likely that a pivoted lodestone spoon was used for divination in the first century A.D. Well before 1100 the true compass—apparently developed earlier for geomantic siting—was being used in navigation, and the declination of the needle was known to steersmen as an effect, if not as a concept.

Bacon's statement about the springs of change in the West reminds us, then, that for many centuries Europe was on balance a beneficiary of technology transfers. Through the long centuries in which Europe gradually relearned the arts of civilization after the Roman Empire collapsed, China continued to build on its high culture. Many important inventions that apply the power of water or wind to machines are first found in Europe more than ten centuries later than in China. A few Chinese priorities of other types are an efficient harness for draft animals, the drawloom, deep borehole drilling, the segmental arch bridge, rigging that allowed ships to sail to windward, the axial rudder, porcelain, and cast iron.

A Chinese visiting one of the great cities of Europe in 1400 would still have found it backward. In Bacon's lifetime some Occidental cities could no longer be considered backward. By 1840 what appeared glorious about China to its more sophisticated visitors were mainly vestiges of the past.

Some of the reasons for the reversal in technological preeminence are internal to China: centuries of disastrous fiscal and other administrative policies, the remorseless pressure of increasing population, and a large measure of social stability and cultural homogeneity that left traditional values and forms practically unchallenged as the creativity behind them was sapped by intellectual orthodoxies. Other reasons for the reversal arose in Europe, above all a universal quantitative and logical approach to empirical knowledge and practice that gradually redefined nature, reshaped society, and remade human consciousness. In the final reckoning the predominance of Western science and technology cannot be explained by contributing factors entirely within Europe or outside it, for it was built on the intercourse of civilizations.

CHINESE AND WESTERN, TRADITIONAL AND MODERN

It is almost impossible to think about traditional Chinese science and technology without comparing them, explicitly or implicitly, with their present-day analogues. Otherwise it would be difficult even to identify what past activities are of technical interest. Nevertheless, the transforming influence of the scientific and industrial revolutions was so great that the earlier sciences of China and Europe resemble each other more than either resembles the modern variety. It is important, if one is to think clearly about science and technology as worldwide phenomena, to avoid confusing differences between China and the West with differences between traditional societies and societies that have become essentially modern.

Certain aspects of today's technical activity that may appear to be universal are in fact peculiarly European or peculiarly modern. We consider normal, for instance, a sequence of sciences derived from classical Greek schemes of knowledge but formed by the gradual spread in modern times of system and quantification, beginning with physics and moving through chemistry, the life sciences, and ultimately (or so Auguste Comte believed) through psychology, the yet-to-be-achieved exact science of the human mind. In Europe this scheme and its precursors did not, when they arose, describe established structures of knowledge but justified projects to bring them about by creating new institutions and habits of thought.

In China there was, for example, no biology. Observations and theoretical perspectives on the manifestations of life were scattered through a very different grouping of knowledge that I will sketch out below. Alchemists, East and West, set down a great deal of information about chemical processes. How much they learned from physicians and illiterate craftsmen we do not know. In any case the designation of Chinese alchemy as early chemistry ignores the fact that alchemical goals were not cognitive but spiritual. Most topics of modern physics had not been imagined before the demise of traditional Chinese science, and the more old-fashioned subjects—for example, heat, sound, and magnetism—were in China a matter of dispersed experiences and reflections rather than coherent disciplines.

Another practically universal modern assumption is that technology is applied science, that technological progress and economic benefit are the natural end of new scientific knowledge. Before the mid eighteenth century, emerging modern science did not affect technology in Europe. Craft traditions were developed by people who, even as literacy began to diffuse through society, had little access to science and little reason to use it.

The old certainty that the industrial revolution in Western Europe and the United States grew out of the direct application of modern science has come so seriously into question since the 1960s that we are prepared to see a much subtler influence operating since the eighteenth century. Coming out of the new Western mentality shaped by theoretical science, this influence led the educated to take an active interest in manufacturing and led artisans (along with everyone else) to begin reasoning impersonally and abstractly about facts, processes, commodities, and labor to an extent unprecedented in human history. The design of economic systems to exploit new scientific knowledge is, at least outside the chemical industry, mainly a twentieth-century phenomenon. Familiar though the direct linkage of science to technology may be to readers of this book, it would have appeared wildly exotic to all except a visionary few three hundred years ago in Europe or Asia.

Since China's industrial revolution began less than two generations ago, what we find previously—as in early Europe—are sciences and manufacturing techniques that had little to do with each other. The sciences reflected the concerns of the tiny literate elite, their cosmologies, and the managerial problems they encountered in their careers and recorded in their writings. Technology was on the whole a matter of craft traditions, passed down privately from father to son or from master to apprentice. It was on these mainly oral and manual traditions rather than on cumulative science, recorded in writing, that the technological preeminence of China was built.

What we know about the early industrial arts comes not from those who did the work but from scholars writing for fellow dilettantes or from officials writing for their peers who happened to be curious about the work of the lower orders. As the learned compiler of the great technological encyclopedia of 1637 put it, "While the best rice is cooking fragrantly in the palace kitchen, perchance one of the princes would wish to know what farming implements look like; or, while the officers of the Imperial Wardrobe are cutting suits of brocade, another of the princes might wonder about the techniques of silk weaving." Those were the circumstances in which a civil servant might actually feel a need for the book. "Let the ambitious scholar toss this book onto his desk and give it no further thought; it is a work that is in no way concerned with the art of advancement in offialdom."[2]

2. Sung Ying-hsing, *T'ien-kung K'ai-wu: Chinese Technology in the Seventeenth Century*, trans. E-tu Zen Sun and Shiou-chuan Sun (University Park: Pennsylvania State University Press, 1966), xiii–xiv (translation modified). Another translation of the technological encyclopedia worth consulting is Li Ch'iao-p'ing et al., trans., *Tien-kung-kai-wu: Exploitation of the Work of Nature*, Chinese Culture Series, no. 3 (Taipei: China Academy, 1980).

Thus in both China and Europe before modern times science and technology went their own ways. Natural philosophers learned from the techniques being practiced around them, at least to an extent that their practical curiosity dictated, but what they read in books counted for a great deal more. The achievements of artisans did not depend on the enhanced scientific understanding of their betters.

SCIENCE AND SCIENCES IN CHINA

In Europe since classical times the various sciences were part of a single structure that included all systematic rational knowledge. They were part of *scientia,* the part that has to do with nature. When in the early seventeenth century Francis Bacon (1561–1626) in England began inventing a physics to which experiment was the key to learning what was fact and what was not, and Galileo Galilei (1564–1642) in Italy imagined a universe full of physical motions that could be measured and computed, these two styles of science—the experimental and the mathematical—developed separately for a while. But they were still seen as parts of one endeavor.

In China there was no single structure of rational knowledge that incorporated all the sciences. Knowing was an activity in which the rational operations of the intellect were not sharply disconnected from what we would call intuition, imagination, illumination, ecstasy, aesthetic perception, ethical commitment, or sensuous experience. The various sciences, unlike those of Europe, were neither circumscribed by the philosophies of their time nor subordinated to theology (which did not exist in East Asia). The sciences developed a great deal more independently of each other than in the West. The practitioners of each science extended and revised the concepts and assumptions about physical reality with which that science began (the particular sciences emerged between the second century B.C. and the first century A.D.). Over the centuries they seldom responded directly to contemporary philosophic innovations. For example, Chu Hsi (1130–1200), perhaps the most influential moral philosopher of the last two thousand years, was intensely interested in astronomy and cosmology, but what he knew of these fields was grossly outmoded; astronomers returned the compliment by ignoring his frequently odd opinions about the sky. They were free to exert that autonomy because no institution enforced the authority of Chu Hsi over them. There is an obvious contrast with the educational institutions of Europe, from Plato's Academy and Aristotle's Lyceum to the medieval and early modern universities, in which the natural sciences were kept subordinate to philosophy.

Although in China the sciences were relatively autonomous provinces of knowledge, there were definite limits to what was expected of them.

Scientists were well aware of the growth of understanding and of the increasing ability to predict, but we do not find the conviction that in the fullness of time all phenomena would yield their ultimate secrets. The typical belief was rather that natural processes wove a pattern of constant relations too subtle and too multivariant to be understood completely by what we would call empirical investigation or mathematical analysis. Scientific explanation merely expressed, for finite and practical human purposes, partial and indirect views of that fabric. This point was made with great clarity by Shen Kua (1031–1095), a polymath who served as astronomer-royal and who made lasting contributions to practically every science.

> Those in the world who speak of the regularities underlying the phenomena, it seems, manage to apprehend their crude traces. But these regularities have their very subtle aspect, which those who rely on mathematical astronomy cannot know of. Still even these are nothing more than traces. As for the spiritual processes described in the *Book of Changes* that "when they are stimulated, penetrate every situation in the realm," mere traces have nothing to do with them. This spiritual state by which foreknowledge is attained can hardly be sought through traces, of which in any case only the cruder sort are attainable. What I have called the subtlest aspect of these traces, those who discuss the celestial bodies attempt to know by depending on mathematical astronomy; but astronomy is nothing more than the outcome of conjecture.[3]

This understanding did not diminish astronomy in Shen's eyes; he devoted his best energies to improving the calendar. His perspective, far removed from that of the modern scientist, would have been quite comprehensible to his contemporaries in eleventh-century Christendom, although he was applying it to a level of scientific knowledge much more sophisticated than theirs.

To sum up, the Chinese sciences were able to attain a high standard—at times the highest in the world—without the overarching structure of natural philosophy that subsumed science in Europe and without the naive claims to universal knowledge that modern positivists have sometimes attempted to read back into the Western tradition.

THE CHINESE SCIENCES: QUANTITATIVE

It will be clear by this point that a catalogue of priorities torn out of context can only give a distorted impression of what is worth knowing about

3. Hu Daojing, ed., *Meng-ch'i pi-t'an chiao-cheng* [Brush talks from Dream Brook], modern variorum ed., 2 vols. (ca. 1090; Peking: Chung-hua Shu-chü, 1960), item 123. For a more extensive discussion of Shen's attitude, see Nathan Sivin, s.v. "Shen Kua," in *Dictionary of Scientific Biography*. An earlier astronomical passage of similar purport is translated in Nathan Sivin, *Cosmos and Computation in Early Chinese Mathematical Astronomy* (Leiden: Brill, 1969), 61–62.

science in China. Regardless of how clearly certain features of early science may appear to anticipate today's knowledge, their contemporary meanings had little in common with those of modern science. In describing the sciences below, therefore, I pay as much attention to context as to accomplishment. The Chinese sciences will be portrayed, in other words, not as a succession of triumphs of objective knowledge abstracted from a morass of superstition but as one important thread firmly woven into the fabric of culture.

The sciences described will be those the Chinese defined by applying their concepts of order to various areas of experience—the sky for astronomy and astrology, the bodies of humans and animals for medicine, and so on. As I have already pointed out, this is a very different demarcation from that of modern science.

Mathematics

It is an old Western habit (which those mathematical pioneers, the ancient Mesopotamians, did not share) to think of mathematics as a quintessentially pure science dedicated to the fundamental exploration of number and extension, with practical applications a matter of little interest to the most esteemed sort of mathematician. In China mathematics was not the queen of the sciences but their servant.

Nearly one thousand Chinese mathematical treatises, beginning in the second century A.D. or a little earlier, survive from previous centuries. The great majority have to do with practical matters of the kinds officials, their clerks, and landowners (and increasingly, in the last ten centuries, merchants) would encounter: surveying, determining areas and volumes, calculating exchange rates and taxes payable in money and commodities, and figuring costs of transportation, materials, and labor. Techniques remained numerical and algebraic, with trigonometric approximations that made it possible from the eleventh century on to do much of the work of geometry with no more need to visualize figures in space than one would need today when solving simple problems on a calculator.

A severely logical and axiomatic corpus of proofs like that of Euclid never emerged to provide a unifying standard of rigor in the quantitative sciences. One cannot argue that national character ruled such rigor out, for we find the beginnings of a universal set of definitions, spanning science, language, ethics, and other fields, in the surviving writings of the abortive Mohist school (ca. 300 B.C.). That some Chinese were capable of constructing geometric proofs is clear from surviving examples beginning in the third century A.D., but this remained as minor a concern as numerical procedures were in Europe before algebra was introduced from the Orient beginning in the thirteenth century.

Chinese mathematics was instrumental from the start. At first, problems were set up with computing rods on a surface ruled off in squares

Figure 7.1. Example of matrix algebra notation from a textbook of 1303. The leftmost of these three simultaneous equations corresponds to $-2x + 2y + z = 15$. The equations are written from top to bottom, and a negative coefficient is indicated by a diagonal slash. Figures 7.1 through 7.5 are reproduced from Joseph Needham, *Science and Civilisation in China* (Cambridge, 1954–), by permission of Cambridge University Press.

like a checkerboard. As the rods were manipulated in appropriate squares, the counting board could represent a two-dimensional array of numbers (figure 7.1). The potentialities of this device were gradually exploited until by ca. 1300 it was being used to manipulate the coefficients of equations in several powers of up to four unknowns. By that time the counting board was being replaced by the abacus, an instrument roughly as speedy as but no more flexible than an early twentieth-century adding machine, and extremely well suited to the routine needs of the growing urban merchant class. Because the abacus could only represent a dozen or so digits in a linear array, it was useless for the most advanced algebra until it was supplemented by pen-and-paper notation. There were few important innovations at the highest level of mathematics from the mid fourteenth century until the seventeenth century, when the Jesuit missionaries prompted an efflorescence of interest in European geometry, true trigonometry, logarithms, and so on. This hiatus may have been part of the price paid for the convenience of the abacus.

The predominantly practical orientation of Chinese mathematics made it neither inferior nor superior to the Western tradition. Its lack of development at the abstract geometric level was balanced by its strength in numerical problem solving. Algebra reached Europe ready-made after it had emerged from a long process of convergent discovery and interaction in China, India, and the Islamic world. Many comparatively late European "discoveries," such as Pascal's triangle of coefficients (published in 1665, but known in the sixteenth century) and Horner's method for solving numerical higher equations (1819), were, we now know, named in ignorance of their Chinese origins (the former ca. 1100 or earlier, the latter ca. 1245).

There was a theoretical and speculative side of Chinese mathematics that modern historians have generally ignored, at some cost to our understanding of what the art meant to its practitioners. The senses of both words used for mathematics before modern times, *shu* and *suan,* include numerology. They refer as well to a variety of divination techniques that identify regularities—not necessarily quantitative—underlying the flux of natural phenomena.

Often, especially in the early centuries of mathematics, prognosticating the future and divining the hidden were thought to be among the powers of master computators. There is an obvious parallel with the complementarity of mathematical astronomy and astrology, which we find not only in China, India, and Islam, but in the West as late as the time of Kepler. The form of the relationship of course varied with the intellectual and social character of the two activities in each culture.

Mathematical Astronomy

According to the Chinese theory of monarchy, the ruling dynasty remained fit to rule because of the accord the emperor maintained with the cosmic order. This accord depended on his personal virtue and his correct performance of certain rituals. His special status in the order of nature enabled him to maintain a corresponding order in the political realm, for the state was a microcosm. If the emperor lacked virtue or was careless in his duties, disorderly phenomena would appear in the sky or elsewhere in nature as a warning of potential disaster in the political sphere.

This theory divided celestial phenomena into those that were regular and could be computed and those that were irregular and unpredictable and thus omens. Astronomers had two tasks. First, mathematical astronomy (*li*) was to incorporate as many phenomena as possible in a correct calendar—actually an ephemeris that included, in addition to days and lunar months, predictions of planetary phenomena and eclipses. Second, astrology (*t'ien-wen,* which in modern Chinese has come to mean astronomy) was to observe unpredictable phenomena and to interpret their political meaning. Thus, the emperor could be warned that all was not well in his realm, so that he could mend his ways and take appropriate administrative measures—or be reassured if the omen was favorable.

The calendar, issued in the emperor's name, became part of the ritual paraphernalia that demonstrated his dynasty's right to rule (a function not entirely different from that of economic indicators in a modern nation). Astrological observations could easily be manipulated and thus could be dangerous in the hands of someone trying to undermine the current dynasty (the analogy with economic indicators is again obvious). It was therefore a principle of state policy that the proper place to do astronomy was the imperial court. In certain periods it was illegal to do it elsewhere.

The most sophisticated accomplishments of Chinese mathematics are largely concentrated in astronomical and chronological reckoning. Astronomers' ability to use what amounts to higher-order equations, to deal with apparent rather than mean celestial motions, and to determine astronomical constants with great precision grew steadily until the ephemerides reached their zenith shortly before 1300. Although lunar eclipses could be predicted with considerable accuracy by 100 B.C., the lack of the spherical geometry or trigonometry needed to calculate accurately the intersection of the moon's shadow cone with the earth's sphere made solar eclipses an abiding problem. The tendency of the imperial court to look abroad for technicians who could deal with it was fateful for the development of astronomy within China, as we will see below. Beneath the steady evolution of computational astronomy over two thousand years in China lay a foundation not only of observational instruments but of data recording systems for centuries on end. Joseph Needham has summarized what is characteristically Chinese in this foundation:

1. The elaboration of large and complex observational and demonstrational instruments, from at least the second century B.C. to the great bronze armillaries of 1421 still on display at the Purple Mountain Observatory, Nanjing (figure 7.2).
2. The invention of the clock drive, and perhaps of the clock escapement itself, in a long series of great astronomical clocks culminating in the eleventh century. A water-driven mechanism rotated an armillary sighting tube for observation, a celestial globe, and a variety of time indicators (figure 7.3).
3. The maintenance of accurate, dated records of such phenomena as eclipses, novae, comets, and sunspots over a longer continuous period than in any other civilization.
4. Early star catalogues embodying quantitative positional data (the earliest possibly from the fourth century B.C., with extant observations from ca. 70 B.C.). No less important, although not as old

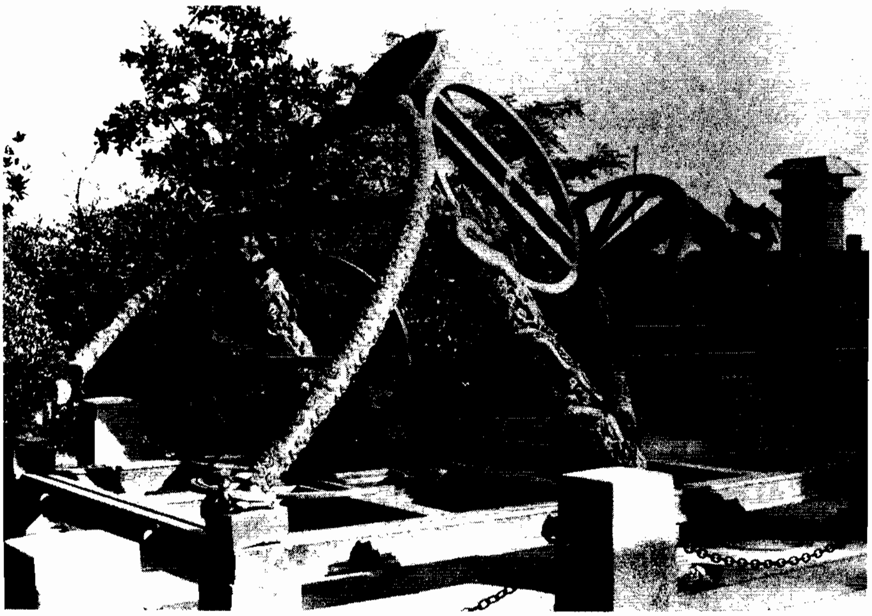


Figure 7.2. "Abridged armillary sphere" of 1421, now at the Purple Mountain Observatory, Nanjing.

as Mesopotamian cuneiform records, are a recently excavated second-century ephemeris and a table of planetary motions from 244 B.C. to 177 B.C.

5. A coordinate system mainly oriented on the equator and the equatorial pole, unlike the ecliptic system prevalent in Europe and Islam until it was replaced in the late sixteenth century with a system like that used in China.
6. Among several early Chinese conceptions of the universe, one in which it was boundless and in which the stars floated in empty space. Perhaps because of its audacity, the details of this cosmic scheme were lost early, and no influence on astronomical practice has been documented.[4]

Despite the limitations of pretelescopic observation, ancient astrological records have proved useful in many ways to modern astronomers. The orbital periods of such celestial bodies as Halley's comet and the frequency of sunspot cycles have been determined with confidence;

4. Based on Joseph Needham, *Science and Civilisation in China,* 7 vols. projected (Cambridge: Cambridge University Press, 1954–), 3:458; for a fuller discussion and references see Leo Goldberg and Lois Edwards, eds., *Astronomy in China: A Trip Report of the American Astronomy Delegation* (Washington, D.C.: National Academy of Sciences, 1979), chap. 2.

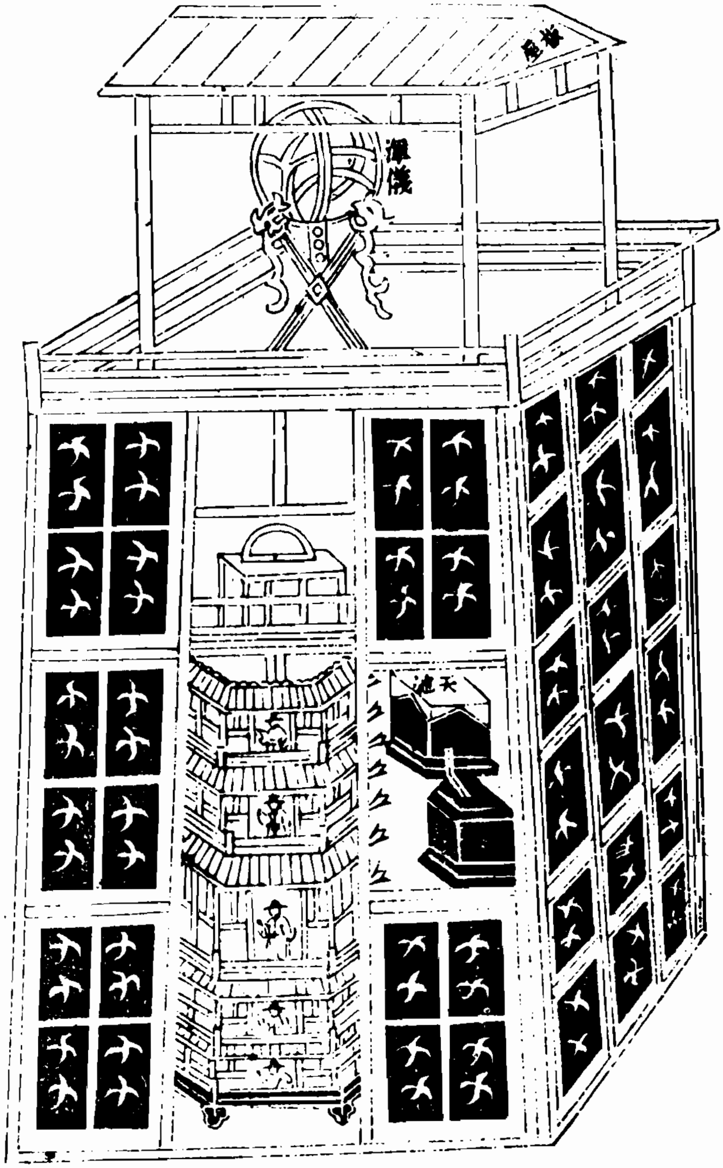


Figure 7.3. Water-driven astronomical clock from a book of ca. 1089.

detailed descriptions of supernova explosions that coincide with today's radio sources have been compiled.[5]

Chinese records have been most productive, supplemented primarily by those of Japan, Korea, and the Islamic world. European records have proved less useful for most of these purposes, since the churchmen and educated laymen who knew astronomy between the late Middle Ages and the seventeenth century generally accepted the Aristotelian dictum that there could be no change in the skies beyond the sphere of the moon. Comets and similar phenomena were considered events below the sphere of the moon (meteorological, more or less) and thus usually not worth noting.

A good part of the historical research under way in the People's Republic of China is devoted to exploring early records for information that bears on current scientific problems. Because of the wide scope of recorded astrological portents, the fruit of this labor has benefited other disciplines besides astronomy. For instance, over the past quarter century three major projects have resulted in detailed tables of earthquakes across the breadth of China and through its recorded history.[6]

Mathematical Harmonics

The third of the quantitative sciences studied the mathematical relations between sounds and the physical arrangements that produced them. The Pythagoreans in the sixth century B.C., it has often been said, motivated two and a half millennia of scientific exploration with their conviction that number and measure underlay the order perceptible in nature, even those aspects of it that appeared purely qualitative. The Pythagorean faith arose from the discovery that the main musical intervals produced by plucking strings of different lengths are related by simple ratios (a string half as long produces the octave, one two-thirds as long gives the fifth, and so on). Chinese harmonics was a similar blend of mathematics and numerology and was concerned with the dimensions of

5. For citations of Chinese research see Nathan Sivin, "Current Research on the History of Science in the People's Republic of China," *Chinese Science* 3 (1978): 39–58. David H. Clark and F. Richard Stephenson, *The Historical Supernovae* (Oxford: Pergamon Press, 1977), discuss ancient star explosions.

6. Chinese Academy of Sciences, Earthquake Working Committee, Historical Group, *Chung-kuo ti-chen tzu-liao nien-piao* [A chronology of materials on Chinese earthquakes], 2 vols. (Peking: Science Press, 1956); Chinese Academy of Sciences, Institute of Geophysics, *Chung-kuo ti-chen mu-lu* [A chronological list of Chinese earthquakes], 2 vols. (Peking: Institute of Geophysics, 1970; reprint, 1 vol., Washington, D.C.: Center for Chinese Research Materials, 1976); Hsieh Yü-shou and Ts'ai Mei-piao, eds., *Chung-kuo ti-chen li-shih tzu-liao hui-pien* [Collected materials on the history of Chinese earthquakes], 5 vols. (Peking: Science Press, 1983–). On the use of historical compilations in theoretical studies see J. Tuzo Wilson, "Mao's Almanac: 3,000 Years of Killer Earthquakes," *Saturday Review*, 19 Feb. 1972, 60–64.

resonant pipes. These pitch pipes provided the standards for ritual bells and stone chimes.

The approaches in East and West were by no means the same. Whereas the Pythagoreans proceeded by subdividing the octave, the Chinese multiplied the string lengths repeatedly by either 2/3 or 4/3 to generate a series (or "spiral") of fifths within the octave. The attempt to draw the most general significances of harmonics was equally ambitious at both ends of Eurasia. To give only one example, the Chinese adapted the pitch pipes as metrological standards of length, volume, and (indirectly) weight.

Harmonics in China is of interest not only for its use in connecting number and nature but for its application in musical performance, above all in the ceremonial music of the court. Music, like astronomy, was cultivated as an aspect of the imperial charisma.

In 1978 a set of sixty-five elaborate bronze chime bells with gold-inlaid inscriptions was unearthed in a tomb dated from the fifth century B.C. The bells produce tones over a range of five octaves; each bell produces two related tones when struck in two different places, a feat that involved remarkably sophisticated trial-and-error design by almost certainly illiterate craftsmen.[7]

THE CHINESE SCIENCES: QUALITATIVE

Most of the aspects of natural order studied in early science were not governed by number and measure. The patterns of function and dysfunction in the human body, for instance, could be accounted for only by qualitative theories. In the early West such theories incorporated a variety of explanatory entities, among them Empedocles' four elements and schemes of pneumata, exhalations, and humors. Such concepts labeled the aspects of a given thing or activity and thus divulged what it had in common with, and how it differed from, other things or activities that could be so analyzed.

By A.D. 200 at the latest, Chinese thinkers had elaborated two main ways to distinguish the phases of a process in time or a configuration in space. Temporal processes in nature were generally considered cyclical, and configurations were thought of as finite. One important theoretical entity was the complementary pair yin and yang, which when applied to processes stood for their taking and giving, abiding and transforming,

7. See Sinyan Shen, "Acoustics of Ancient Chinese Bells," *Scientific American* 256, no. 4 (April 1987): 104–10. For the theory of tuning to which these bells were adapted, see Cheng-Yih Chen (Ch'eng Chen-i), "The Generation of Chromatic Scales in the Chinese Bronze Set-Bells of the −5th Century," *Science and Technology in Chinese Civilization*, ed. Cheng-Yih Chen (Singapore: World Scientific, 1987), 155–97.

retracting and expanding, relaxing and stimulating aspects, and when applied to configurations stood for the ventral and dorsal, lower and upper, inner and outer aspects and analogous functions that could be thought of as feminine and masculine pairs. Yin and yang were without exception relational conceptions. As a modern textbook of traditional medicine puts it, "Considering the relation of chest and back, the chest is yin and the back yang; but when associating chest and abdomen, the chest, being above, is assigned to yang, and the abdomen, below, to yin." Similarly, yin and yang did not necessarily correspond to female and male; an old man may be yin when compared with a young man, and a young woman yang when compared with an old woman. Something is yin or yang only in reference to an ensemble of which it is a part.[8]

In addition to resolving any whole into its yin and yang aspects, one could understand it in terms of a similar system of five phases (*wu-hsing,* often mistranslated as "five elements" by false analogy with the Greek four elements). This understanding was not different from yin and yang but merely finer textured. In cycles of change the phases labeled "water" and "fire" stood for the most intensive aspects of yin and yang; "metal" and "wood" stood for the less intensive aspects; and "earth" stood for the aspect in which the opposed tendencies were balanced and in effect neutralized each other. The use of the five phases in the study of spatial relations was analogous. Most commonly four of the five stood for the cardinal points of the compass and the quarters of the sun's annual path corresponding to the four seasons, and earth stood for the central point on which others pivoted. Thus, for instance, in scientific discourse earth always implied balance and the neutral center; it did not refer to particles of earth as ultimate constituents.

Yin-yang and the five phases were not primarily technical concepts. Like the European notion of cause and effect, they belonged to everyday language and were likely to be used whenever anyone tried to explain structure and change. At the same time, like cause and effect they had more specialized meanings in learned discourse. As each of the qualitative sciences assumed its classical form, yin-yang and the five phases were given special definitions related to the subject matter of that field and were supplemented with other technical conceptions to provide a language adequate for theory. Because the sciences evolved independently, the exact meanings of common concepts tended to differ considerably from one discipline to another.

8. Kwangchou Armed Forces, Rear Support Units, Medical Administrative Organization, *Hsin-pien Chung i-hsueh kai-yao* [New essentials of Chinese medicine] (Peking: People's Hygiene Press, 1972), 2. This work is translated in Nathan Sivin, *Traditional Medicine in Contemporary China,* Science, Medicine, and Technology in East Asia, no. 2 (Ann Arbor: Center for Chinese Studies, 1988), 203.

Astrology

Mathematical astronomy has been described above as the science of celestial phenomena that can be predicted and thus need not be observed. Astrology, its complement, depended on data available only through contemplating the sky. It sought to discern the significance of unpredictable phenomena for current politics, interpreting observed data in part by precedent and in part by theoretical analysis.

In the standard histories published by successive dynasties we find records of a great variety of phenomena involving solar eclipses, sunspots, the stars and planets, and comets, as well as what would now be considered atmospheric phenomena and terrestrial prodigies. The character of the record and its contemporary use are perhaps best revealed by example. Here is the account of the great supernova of 1006 from the treatise on astrology in the official history of the Sung dynasty. It is one of several accounts in Chinese sources that, when pieced together, provide rich data on the supernova and allow its identification with a present-day radio source.

> On the fifteenth sexagenary day, fourth month, third year of the Luminous Virtue reign period [May 6, 1006], a Chou-po star appeared. It emerged in the south of the lunar lodge Base, 1° west of the constellation Mounted Guard [twenty-seven stars, mostly in Lupus]. Its form resembled that of the half-moon, and it had pointed rays. It glowed so brightly that objects could be distinguished by its light. It passed to the east of the constellation Treasury-and-Tower, and in the eighth month, following the rotation of the sky, "entered the turbid zone" [i.e., set with the sun and thus became invisible]. In the eleventh month it appeared once again in Base. Thereafter it was seen regularly heliacally rising in the east in the eleventh month and setting in the southwest in the eighth month.

Earlier in the same treatise the astrological characteristic of a Chou-po star, one of five canonical classes of auspicious stars, is noted in long-established language: "A Chou-po star is yellow in color and brilliant; the state in correspondence to which it appears will greatly prosper." The last phrase refers to a system of interpretation in which each part of the sky corresponds to an area of China. Where the manifestation appears indicates the part of the country affected. This instance corresponds roughly to modern Honan province.

Astrological interpretations are neither mumbo jumbo nor unsuccessful science. They are best understood, like modern economic indicators, as a technical framework for policy debates, resolved, as often as not, on other grounds. Faith in the validity of astrological categories, like confidence in extensively manipulated statistics today, persists despite their repeated failure to deliver accurate predictions.

In the biography of Chang Chih-po, an imperial commissioner in

1006, there is a fragment of the discussion that followed the appearance of a new star. We find Chang attempting to turn the attention of the court away from the auspiciousness of the omens and the details of interpretation toward the moral vigilance of the monarch, which Chang urged should not be relaxed at moments of good tiding:[9]

> When the Chou-po star appeared, the astronomer-royal reported it as an auspicious portent. The court officials prostrated themselves at the palace gates to offer congratulations. Chang expressed the view that the Ruler of Men ought to cultivate his virtue in response to the celestial phenomena, but that the appearances and disappearances of such stars had no particular significance [literally, "were not tied to anything"]. He proceeded to outline the essentials for mastering the Way [of correct government].

These essentials, we can be sure, supported the politics that Chang favored.

The inseparability of astrology from politics should not be taken to imply that the former was less pure a science than mathematical astronomy. Their institutional setting was the same, at least until classicists outside government circles in the seventeenth century took up the computation of ancient eclipses and other phenomena to understand early technical writings, correct the chronology of the Confucian scriptures, and test their authenticity. In early astronomy the great concentration of effort on solar eclipses, the relative neglect of such interesting topics as latitude theory and apparent planetary longitudes, and the use of gnomon-shadow observations for many centuries after armillary instruments had surpassed the gnomon in accuracy all represent the direct imprint on mathematical astronomy of court ritual patterns and the social norms behind them. The difference between astronomy and astrology was a contrast of emphasis on the quantitative as opposed to the qualitative and on objective motions as opposed to the correlation between celestial and political events.

Medicine

The data collected over the centuries about the body, health, and disorders were structured by the concepts of nature described earlier, form-

9. The three translations are from *Sung shih* (Standard history of the Sung period) (Peking: Chung-hua shu-chü, 1977), 56:1226, 52:1076, and 310:10,187. For additional sources and excellent discussions based on freer translations see Bernard R. Goldstein and Ho Peng Yoke, "The 1006 Supernova in Far Eastern Sources," *Astronomical Journal* 70 (1965): 748–53. For a worldwide study drawing on Goldstein and Ho, see Clark and Stephenson, *The Historical Supernovae*, 114–39. The lunar lodges were twenty-eight divisions of the sky along the equator that were used for recording locations of astronomical events. Base, one of these lodges, was centered about R.A. 14h 20m, and the brightest stars in Mounted Guard (mostly in the Western constellation Lupus) were between −35 and −40 degrees in declination. Treasury-and-Tower was a group of about ten stars in Centaurus.

ing a coherent body of theory used to diagnose and treat illness.[10] Classical medicine deserves the adjective "scientific" no less (but no more) than its counterparts in Western culture until recent times. It provided health care for a small portion of the Chinese populace. The majority of its patients and its more eminent practitioners belonged to the upper crust of society. Most of the afflicted among the Chinese population over the course of history had no access to the few fully qualified physicians. They depended on a great variety of less educated healers, ranging from herbalists to priests—a situation that would have been perfectly familiar in eighteenth-century France.[11]

What we call medicine incorporates and imposes order on experience related to every aspect of health, disease, and injury. One Chinese scheme of the major divisions of medicine included theoretical studies of health and disorder; therapeutics; the theory and practice of longevity techniques, including sexual hygiene; pharmacognosy; and veterinary medicine. Pharmacognosy, the study of vegetable, animal, and mineral substances used in therapy, brings together so much information on the sources and characteristics of thousands of drug ingredients that its literature was studied not only for therapeutic purposes, but also as compendia of natural history.[12] Prescriptions made up of both crude drugs and extracts were commonly used in combination with a great variety of other therapeutic means, including acupuncture and moxibustion, dietary regulation, calisthenics, breathing exercises, and massage.

In acupuncture needles were inserted into the flesh at certain points; in moxibustion cones of punk were burnt on the skin at those points. These stimuli affected what traditional physicians considered a circulation of vital fluid throughout the body (figure 7.4) and what clinical researchers today in China and abroad are more inclined to see as peripheral nerve endings and receptors. On the whole, acupuncture was classically considered a minor component of therapy, usually effective

10. The general level of Western publications on Chinese medicine is extremely low. The only penetrating analysis of classical medical concepts in any European language is Manfred Porkert, *The Theoretical Foundations of Chinese Medicine,* MIT East Asian Science Series, no. 3 (Cambridge, Mass.: MIT Press, 1974). For a Chinese outline of medical doctrine see Sivin, *Traditional Medicine in Contemporary China,* 201–427. The sections of *Science and Civilisation in China* on medicine are not yet in press. Several excellent essays by Needham in collaboration with Lu Gwei-djen have been gathered in *Clerks and Craftsmen in China and the West: Lectures and Addresses on the History of Science and Technology* (Cambridge: Cambridge University Press, 1970), in particular "Medicine and Chinese Culture," 263–93.

11. The only substantial study that looks beyond classical medicine to the diversity of health care in early times is Paul U. Unschuld, *Medicine in China: A History of Ideas* (Berkeley: University of California Press, 1985).

12. Paul U. Unschuld, *Medicine in China: A History of Pharmaceutics* (Berkeley: University of California Press, 1986), gives information about a large part of this literature.

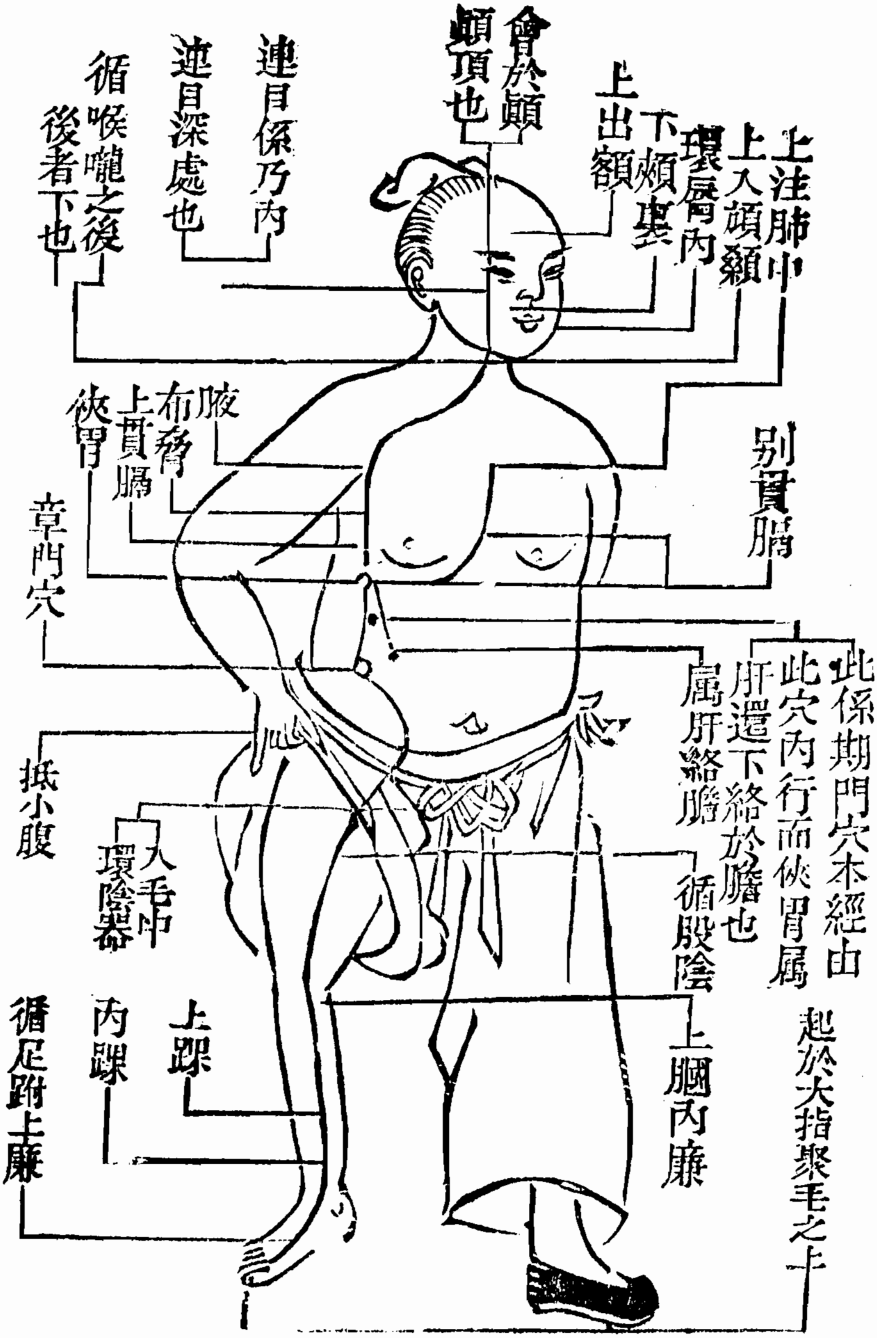
only for certain disorders and when continued over a long period. In modern Chinese clinical practice it is of course impossible to evaluate acupuncture separately from the other Chinese and Western remedies with which the patient is treated.

Acupuncture has been promoted to the status of wonder cure by the American media in their restless quest for novelty. It has proved attractive out of proportion to the rest of traditional therapy. It is exotic to Americans, who were very late in learning about its long-standing popularity in East Asia. Few know about its use in Europe for roughly three hundred years or its vogue among physicians in early nineteenth-century America.[13] It is usually confused with acupuncture anesthesia (or analgesia), a new technique used in modern surgery since the late 1950s. In traditional surgery (limited to external medicine, amputation, and bonesetting), the only anesthetics we know to have been used were drugs—mainly alcohol, datura, and cannabis.

Classical Chinese medicine has often been represented as an empirical science based on the clinically sound use of effective natural drugs and other remedies. In this view, theories served primarily as mnemonic devices or as mystifications to confuse the untrained. Some modern physicians who have not troubled themselves to study classical medical doctrines dismiss them as futilities of the feudal past. Other authors have portrayed classical medicine as a remarkable corpus of theory—based on adaptations of the yin-yang and five-phases concepts—that succeeded in understanding the body as a many-leveled system and treated its ills holistically. They accordingly recommend it as a corrective to the impersonal, excessively lesion-centered and nihilistic tendencies of modern biomedical therapy. The mild and usually nonspecific remedies of traditional medicine are sometimes, but by no means always, expected to contribute to this reform. A closer acquaintance with the literature of classical medicine and with its practice in today's China suggests that these are partial pictures of a more complicated reality.

Before 1920 the strengths of medicine everywhere lay predominantly in the care of mild and chronic disorders. There was little physicians could do for most acute emergencies beyond strengthening the patient's defenses and preparing his family for the worst. With that emphasis on mild and chronic cases in mind, we are better able to judge the importance of gentle, gradual remedies, practices aimed at evaluating and improving the physical, mental, spiritual, and social circumstances of the patient, and theories used to relate symptoms to a multitude of therapeutic measures, both to design a flexible program of therapy and to

13. James H. Cassedy, "Early Uses of Acupuncture in the United States, with an Addendum (1826) by Franklin Bache, M.D.," *Bulletin of the New York Academy of Medicine*, 2d series, 50 (1974): 892–906.



上注肺中
上入頏顙
環唇內
下頰裏
上出額
會於巔
巔頂也
連目係乃內
連目深處也
循喉嚨之後
後者下也
腋
布脅
上貫膈
挾胃
別貫膈
章門穴
此係期門穴本經由
此穴內行而挾胃屬
肝還下絡於膽也
屬肝絡膽
抵小腹
入毛中
環陰器
循股陰
上膕內廉
上踝
內踝
循足跗上廉
起於大指聚毛之上

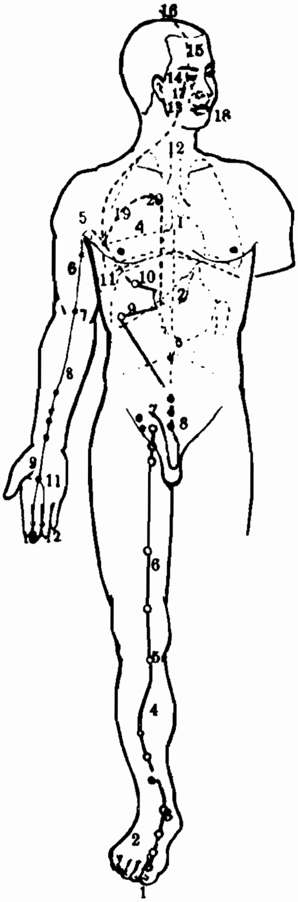


Figure 7.4. Similar diagrams of acupuncture loci from an eighteenth-century source and a textbook of 1960.

make those relations comprehensible to the patient. Theory also maximized control of acute disorders by emphasizing prevention and early treatment.

That Chinese medicine does not give a detailed and accurate picture of anatomy and physiology was not a handicap. The high state of anatomical knowledge in Europe by the time Andreas Vesalius died in 1564 was the glory of medicine as a branch of academic learning but had little application to medicine as the care of suffering people. It was not until the early nineteenth century that diseases in the living could be connected reliably with abnormalities seen when cadavers were dissected. Surgeons could exploit this knowledge fully only as disease came to be thought of in terms of localized lesions, as asepsis and anesthesia made local intervention safe, and as the organization of the medical profession imposed a single high standard of qualification. In the United States, for instance, the changes that made surgery safe and routine were not well under way until about 1920.

Unlike modern biomedicine, the traditional Chinese art could not draw on anything comparable to modern biology, chemistry, or physics. For that reason, its concepts look more like those prevalent in Europe four hundred years ago. They are not concerned with microorganisms or details of the body's organs and tissues. The strength of classical Chinese medical discourse lay rather in its sophisticated analysis of how functions were related on many levels, from the vital processes of the body to the emotions to the natural and social environment of the patient, always with therapy in mind. Chinese medicine is best evaluated in the light of this strength rather than according to criteria that could not have been applied anywhere until half a century ago.

Alchemy

Chinese alchemy used chemical techniques to prepare elixirs, which were perfected substances that brought about personal transcendence and eternal life. Elixirs could also be used for medical purposes and for transforming ordinary metals into gold. That is how an alchemist might have defined "external alchemy" (*wai-tan*); its analogue, "internal alchemy" (*nei-tan*), used the language of the laboratory to teach meditational (or sometimes sexual) disciplines in which the adept's body was visualized as the reaction vessel and furnace. In the first millennium the two alchemies were regularly practiced together, but after 1200 little activity in the external art was recorded.

The materials and apparatus of alchemy were on the whole the same as those of pharmacology, with some contributions from metallurgy and other practical chemical arts (figure 7.5). Certain developments, such as elaborate distilling vessels, appear so exclusively in alchemical literature that they may have originated there. The same may be said of gunpowder. What may be the earliest mention of flare mixture composition appears, oddly enough, in a list of external alchemists' misguided activities in a treatise on internal alchemy written not later than the end of the ninth century: "There was a case in which sulphur and realgar were mixed with saltpeter and honey, and burnt. Flames leapt up, burning the alchemist's hands and face and incinerating the building."[14]

The roughly one hundred remaining *wai-tan* books are probably the world's richest source for what was known about reactions and their products up to 1200. They reveal, in fact, that alchemy was not entirely

14. *Chen yuan miao tao yao-lueh* [Essentials of the mysterious Tao of the true origin], in *Cheng-t'ung tao tsang* [Collected Taoist works], 596:3a. On this book see Needham, *Science and Civilisation in China*, vol. 5, part 3, 78–79.

Figure 7.5. Commercial distillation of mercury, from the *Technological Encyclopedia of 1637.*

qualitative; some adepts took a lively interest in what weights of reagents would combine to form a new substance.[15]

Knowledge of chemical change was a means and a by-product, not the aim, of external alchemy. For some practitioners the goal was hardly distinguishable from that of medicine. Others were less interested in a product that would bring health or immortality than in the alchemical process, which they designed to serve as a model of the great cycles of nature, the rhythms of the tao.

No mortal could experience the cosmic cycles in their millennial sweep. These alchemists accelerated the scale of time, using theories based on yin-yang, the five phases, and numerology, to create, in a laboratory procedure that might require a few weeks to a year, an object of mystic contemplation. They believed, like the Pythagoreans before them, that to grasp the constant patterns that underlie the phenomenal chaos of experience is to be freed from the bonds of mortal finitude. As in the other Chinese sciences, the motivation that led to chemical discovery was connected to the deepest values of the seekers.

Siting

Masters of geomancy, or siting (to use the more informative term proposed by Steven J. Bennett), analyzed topographic features to find balanced land configurations in which to place houses and tombs.[16] Alchemy, as we have seen, used the yin-yang and five-phases concepts to understand and manipulate time as it shaped certain laboratory processes; siting adapted the same concepts to the study of space and form in the landscape. Some practitioners depended on their experience to judge the visual balance of topography, and some used readings taken with the famous geomantic compass. This instrument, which among its eighteen or more concentric dials (figure 7.6) incorporated indications of magnetic declination, was apparently a forerunner of the sailor's navigational instrument.

Once its contributions to the evolution of the compass are acknowledged, siting is sometimes shrugged off as a mass superstition. There is indeed not a great deal to be said for it if the sole criteria of evaluation are those of science today. But those are not the criteria that lead to understanding, since siting was not as narrowly focused as modern sci-

15. Nathan Sivin, in Needham, *Science and Civilisation in China*, vol. 5, part 4, 300–305. This essay is summarized in "Chinese Alchemy and the Manipulation of Time," *Isis* 67 (1976): 513–26, especially 521; reprinted in Nathan Sivin, ed., *Science and Technology in East Asia*, History of Science, Selections from Isis (New York: Science History Publications, 1977), 117.

16. Steven J. Bennett, "Patterns of the Sky and Earth: A Chinese Science of Applied Cosmology," *Chinese Science* 3 (1978): 1–26.

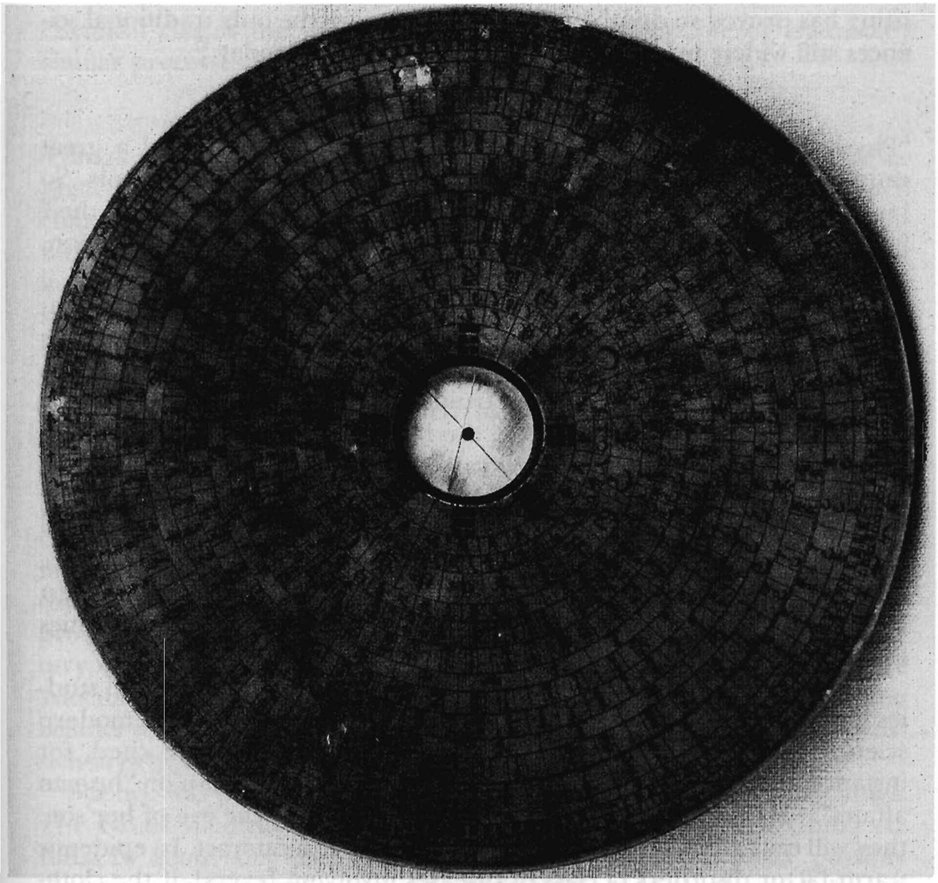


Figure 7.6. A nineteenth-century siting compass, from the author's collection. (Photo by Nathan Sivin)

ence. Siting nevertheless fits the broader definition of a premodern science, for certain schools of practice worked out a system of abstract and objective reasoning about the natural phenomena that concerned them.

Anthropologists have found siting worthy of study because of the way it was used (and is still being used) to resolve conflicts of status between practitioners' clients. Geographers and landscape architects have expressed interest in siting theory because it accomplished for centuries what modern theorists have been trying to do: provide a systematic framework for reasoning that will reliably yield beautiful sites. Because the balance that siting strove for was dynamic and complex, the benefits of the science are in large part aesthetic—not a matter of purely scientific interest, but of no small utility nevertheless. That may explain why siting has proved so durable. It and medicine are the only traditional sciences still widely practiced in Chinese communities today.[17]

Physical Studies

"Physical studies" is a grab bag of traditions that considered a great range of natural phenomena in the light of fundamental concepts. So far these traditions have been little studied, but a great deal in their literatures throws light on early knowledge of change and interaction, whether chemical, physical, or biological.

A few items from the section on trees in one of the most popular treatises suggest the wealth of information to be found there: "If peach is grafted onto persimmon, the fruit will be golden peaches. If peach is grafted onto Japanese apricot, the fruit will be meaty. If male and female gingko trees are planted together, the females will bear fruit. If pomegranate is grafted onto 'flowering cassia' [*Osmanthus fragrans Lour.*], the blossoms will always be red." Because we do not have records left by those who mastered grafting, it is from sources such as this one, as well as writings on materia medica, that the history of Chinese arboriculture must be reconstructed. An analogously broad range of documents must be studied by those who wish to understand many other ancient activities that required technical knowledge.

It would be misleading to leave the impression that the physical studies literature is a trove of information all of which is pertinent to modern science. The mixed character of the tenth-century book just cited, for instance, is obvious from two consecutive items in the section on "human affairs": "When a mother cries and her tears fall into the eye of her son, they will cause damage to its pupil and give rise to a cataract. In epidemic warm-factor disorders [a class of diseases involving fevers], if the clothing of the first person to fall ill is steamed in an earthenware steamer, the rest of the family will not catch the sickness."[18]

The abstract ideas in these extensive compilations also deserve to be investigated. In a study of how yin-yang and the five phases bear on alchemy, P. Y. Ho and Joseph Needham called the ancient application of these ideas "a hitherto unrecorded chapter in the prehistory of the conception of chemical affinity," by which they meant that it "seems to take its place in the linear ancestry of the idea that things can be arranged in

17. Siting is officially considered superstitious and is discouraged in the People's Republic, but it is still practiced. On siting in the New Territories of Hong Kong see Baruch Boxer, "Space, Change and Feng-shui in Tsuen Wan's Urbanization," *Journal of Asian and African Studies* 3 (1968): 226–40.

18. Tsan Ning, *Ke-wu ts'u-t'an* [Simple discourses on the investigation of phenomena] ed. Pai-pu ts'ung-shu chi-ch'eng (ca. 980), 1:4b and 2:16b. Compare the translation in Needham, *Science and Civilisation in China,* vol. 5, part 2, 149.

chemical classes the members of which are susceptible of chemically similar processes."[19]

The Transmission of Science between Civilizations

Things and ideas have flowed between China, Europe, and the other great civilizations regularly since the New Stone Age. Whether such characteristics of the earliest Chinese civilization as writing, the manufacture and use of the wheel, and bronze and iron metallurgy diffused into China from abroad or whether they were reinvented from scratch is still a matter for heated debate. These two hypotheses need not be considered mutually exclusive, for a mere rumor that something exists vastly simplifies making it. In any case the wheel and metalworking did not appear in China fully formed, as we would expect had they been imported.

Wrought iron, for instance, was being made in the mid seventh century B.C., perhaps six centuries later than the wrought iron of Anatolia. Cast-iron objects from the sixth century B.C. have been excavated. Cast iron could not be produced at will in the West for another seventeen centuries. Steel was produced at first from wrought iron, but the industrial processes for making it from cast iron were perfected in the second century B.C. This feat was possible because all the necessary elements were available: efficient furnaces derived from ceramic kilns, reciprocating bellows to provide an air blast, good refractory clays, and phosphorus-rich ores or fluxes to lower the melting point of iron.[20]

Science was part of the flow between East and West from early times. The Greek medical doctrine of the four elements reached China via India by about A.D. 500. Physicians from Byzantium or Syria, possibly Christians, are said to have cured a Chinese emperor in the mid seventh century. Jesuit missionaries in China published a treatise on Western physiology and an anatomical atlas in the mid seventeenth century, but the two books were very little circulated and received practically no attention. The first European book on Chinese medicine was published in 1682, the first on acupuncture in 1683. Alchemical elixirs of Western origin are noted in seventh-century China, and there is some evidence that Chinese alchemical gold was traded or sold abroad. But the greatest foreign scientific influence on China in early centuries, as in the seven-

19. Ping-Yü Ho and Joseph Needham, "Theories of Categories in Early Mediaeval Chinese Alchemy," *Journal of the Warburg and Courtauld Institutes* 22 (1959): 173–210, especially 201; a revised version appears in Needham, *Science and Civilisation in China*, vol. 5, part 4, 322.

20. For a summary of recent research see Tsun Ko [K'o Chün], "The Development of Metal Technology in Ancient China," in *Science and Technology in Chinese Civilization*, ed. Cheng-Yih Chen (Singapore: World Scientific, 1987), 225–43.

teenth-century heyday of Jesuit missionary activity, was exerted in astronomy. A fuller discussion of that field is in order.

Before the middle of the seventh century A.D., after Buddhism had become rooted in China, Indian astronomers worked in the Chinese capital. Their techniques were partly derived from Greek astronomy. They were more reliable for predicting solar eclipses than those current in China. The political significance of solar eclipses led the Chinese court from the turn of the eighth century to depend on resident foreign astronomers. When the Mongols brought China under their rule in the second half of the thirteenth century, their astronomical officials were Islamic, from Persia and Central Asia. Their computational procedures were more accurate than those of their Indian predecessors. Muslims were still performing the same services for the court when Jesuits began competing with them three hundred and fifty years later.

The Jesuit missionaries in China in the early seventeenth century were there not to propagate astronomical science but to convert the empire from the top down to Roman Catholicism. The only established access to the top was in the Astronomical Bureau, which had provided court positions to foreigners for nearly one thousand years. By 1645 the Europeans had gained operational control of the bureau after submitting to the throne a series of treatises that set out in Chinese the mathematical and cosmological foundations of European astronomy and winning several dramatic eclipse prediction contests. They maintained their status in the astronomical civil service past the middle of the eighteenth century.

The church's injunction against teaching the Copernican doctrines of the central sun and the planetary earth in 1616 and the condemnation of Galileo in 1633 made it impossible for the missionaries to disseminate the state of the art as it developed over the next century or so or to explain fully what the accomplishments of Copernicus, Kepler, and Newton had been. As the new astronomy evolved, discussions of it in Chinese by Jesuit writers before 1760 were thus full of gaps and contradictions, which were never explained. What is often considered the great watershed in European scientific consciousness was not revealed in China until late in the nineteenth century, long after it had become commonplace in the West. Nor were the Jesuit writings sufficiently technical and detailed to permit the Chinese to advance world knowledge. Nevertheless, they stimulated a high pitch of astronomical activity.

The geometric and trigonometric approaches and the cosmological framework of the Jesuit writings in Chinese, obsolete though they became as the seventeenth century wore on, precipitated what can only be called a scientific revolution. The best Chinese astronomers of the time (who mainly worked outside the imperial court) adopted new concepts, tools, and methods. They changed their convictions about what constituted an astronomical problem and what significance astronomy could have for the ultimate understanding of nature and even of human society.[21]

This metamorphosis of astronomy did not lead to the fundamental changes in thought and society that are naively supposed to be the inevitable outcomes of a scientific revolution. Conceptual revolutions, like political revolutions, occur at the margins of societies. The astronomers who responded to the Jesuit writings were members of the educated elite who above all felt the responsibility for strengthening and perpetuating traditional ideas. They were, in other words, at the center of their society. It is scarcely surprising that they used what they learned from the West to rediscover and carry to new heights the astronomical techniques of their greatest Chinese predecessors.

Only after the Opium Wars of the early 1840s could the Chinese receive a systematic education in the exact sciences as then taught in Europe. This time the educators were not individual priests dependent on the toleration of their hosts. They were mostly Protestant missionaries exempt from Chinese laws, their right to operate missions and schools guaranteed by imposed treaties and enforced by gunboats. They were no longer appealing, as the Jesuits had done, to an elite intent on adapting new techniques to traditional ends. The Protestant missionaries educated mostly the poor and people of modest means. Even their richer converts came to them because changes in the civil service gave their children little chance of conventional success in the old society.

Late-nineteenth-century Chinese astronomers trained in Western institutions had no reason even to be curious about what their compatriots in earlier times had done. By 1880 Protestant missionaries, generally working with Chinese, had translated from European languages a number of basic textbooks in astronomy, mathematics, and physics and made them generally available at low prices. Their schools, libraries, bookshops, and other institutions were founded to instigate change, not to preserve Chinese civilization.

As the threat of dismemberment by the colonial powers became more imminent, the Chinese government was belatedly persuaded to begin educating modern scientists. In 1866 a department of mathematics and astronomy was added to the T'ung-wen-kuan in Peking, which had previously been a college for interpreters. In 1867 a translation department was added to the Shanghai Arsenal, which had been established two

21. John B. Henderson, *The Development and Decline of Chinese Cosmology* (New York: Columbia University Press, 1984); Benjamin Elman, *From Philosophy to Philology: Intellectual and Social Aspects of Change in Late Imperial China,* Harvard East Asian Monographs, no. 110 (Cambridge, Mass.: Council on East Asian Studies, Harvard University, 1984); Nathan Sivin, "Copernicus in China," *Studia Copernicana* (Warsaw) 6 (1973): 63–122.

years earlier. There Chinese foreign employees of the imperial government systematically undertook the translation and publication of modern works in science, engineering, medicine, law, and so forth. These and the less systematic technical publications of the missionaries were widely distributed and eagerly studied by amateur groups that maintained the tradition begun by the Jesuit writings. The new translations often played a part in the education of statesmen and reformers, for whom they provided a window on the world. The future lay, however, not with those who saw modern technology as a tool to breathe new life into an empire and a traditional culture, but with those at the margin of the old society, educated in modern schools and given employment in imported institutions.

From about 1900 onward, Chinese astronomers began to emerge who were fully prepared to benefit from advanced training abroad. They were educated in missionary institutions as well as in government universities as these appeared. When ten foreign powers extracted heavy indemnities from China after the Boxer Uprising in 1900, the United States used income from its share to support students during their technical training abroad. Scientists trained in the United States, Europe, and Japan, as well as those educated in China, created the first large-scale system of research institutions and an educational system to train scientists. A few of these institutions were founded by foreigners in the image of their own, but—to redirect the words of a leading historian of China—"on all sides of this gleam of Western light, China was being torn apart by forces so powerful that they made the Westerners' efforts poignantly irrelevant."[22]

Since 1949 China has by fits and starts invented policies toward education and science that reflect its own priorities rather than the expectations of other nations.

THE HISTORY OF SCIENCE IN CONTEMPORARY CHINA

In China today it is normal for scientific journals to publish historical studies, for research centers, observatories, and other organizations to house research groups for ancient science and technology, and for modern scientists to be knowledgeable about their country's scientific heritage.[23] This situation contrasts so greatly with that of most other countries that it calls for an explanation.

I have already noted that early astronomical and earthquake records

22. Jonathan Spence, *To Change China: Western Advisors in China, 1620–1960* (Boston: Little, Brown, 1969), 172.

23. Recent astronomical publications and research are summarized in Sivin, "Current Research."

are a valuable resource for current scientific research. But this is only one motivation for the awareness of history. Other reasons are related to China's place in the world. For millennia the Chinese considered their land the one true center of civilization. Over the past century China has had to make an entirely new place for itself as only one member of a large family of nations. For most of the last one hundred years it has been dependent on and has been looked down on by foreigners for that reason. The present government is resolved to make China independent within limits set by the imperatives of survival and is trying to enlist the energies of every citizen.

China's recent policies for technological development have been unique in many respects. They have made unique demands for adaptation on the part of the whole scientific sector of society, which until a couple of decades ago was considered quintessentially Western. Science and engineering were what one learned from foreigners in order to safeguard oneself against them. This view has gradually been changed over the past twenty years by popularizing the history of Chinese science. Children's books, postage stamps, museum exhibits, and school lessons have all carried the message that science is not European but a world enterprise and that over most of history China was one of the great contributors to that enterprise.

It is not difficult to find this point explicitly stated. Consider the afterword to a book for teenagers on every aspect of technical history, published just after the Cultural Revolution: "The achievements of China's ancient science and technology prove that the Chinese people have the ability needed to occupy their rightful place among the world's peoples. These achievements will also encourage our faith and strengthen our resolve, so that in the shortest possible time we may catch up to and surpass the world's most advanced levels of development. China has yet greater contributions to make to humanity."[24] Scientists and medical researchers experience this consciousness as a close linkage between scientific work and political activity.

Enhanced consciousness of Chinese scientific history is not entirely an internal matter. The importance and fascination of the Chinese scientific tradition have long been known in Europe, Japan, and the United States. Scholars in many countries have contributed to understanding it as well

24. Chinese Academy of Sciences, Institute for the History of Natural Sciences, ed., *Chung-kuo ku-tai k'e-hsueh ch'eng-chiu* [Achievements of ancient Chinese science and technology] (Peking: Chung-kuo Ch'ing-nien Ch'u-pan-she, 1978), 706. Written for teenage readers, this comprehensive work contains contributions by China's best-known historians of science and technology. The sentences translated in the present essay do not appear in the English version, *Ancient China's Technology and Science* (Peking: Foreign Languages Press, 1983).

as to making the work of many great Chinese historians of science accessible in other languages.[25]

Educated people all over the world are now prepared to respond to new revelations about Chinese scientific traditions—whether they be new applications for the ancient art of acupuncture or the unique archaeological finds that have been appearing without interruption since the 1950s. The heightened interest has meant a small but perceptible rise in the world's esteem for China. More to the point, it has meant that scientists all over the world are increasingly involved in the give and take that help Chinese scientists to be fully involved in the international scientific community.

25. Historical scholarship, mainly since 1980, is summarized in Nathan Sivin, "Science and Medicine in Imperial China—The State of the Field," *Journal of Asian Studies* 47, no. 1 (1988): 41–90.