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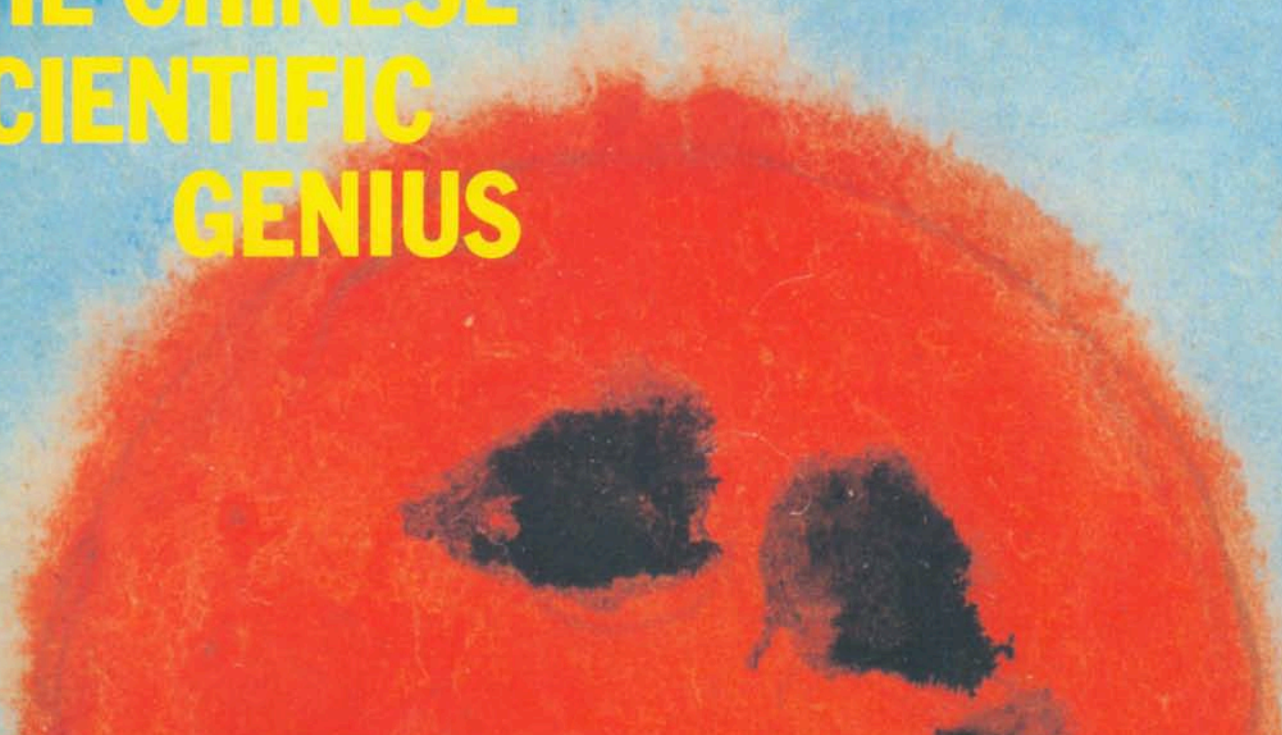
THE CHINESE SCIENTIFIC GENIUS



Discoveries and inventions of an ancient civilization

WEAVING CLOUD BROCADE

These weavers are practising their craft on modern reconstitutions
of a Chinese loom dating from the Ming Dynasty (1368-1644).
Looms of this type, which represent an advanced form of weaving technology, were
used to produce intricately figured fabrics, notably the multi-coloured brocaded silks
with floral and cloud motifs which are known as *yunjin* ("cloud brocade").
While the weaver operates the loom by pressing treadles with his feet,
an operative seated on top of the machine creates the pattern.
Automation of this technique has proved difficult,
and time-honoured methods are still used to produce this kind of brocade.

October 1988

Cover: Illustration of sunspots from a manuscript by the Ming Emperor Zhu Gaoji (Xuanzong) entitled *Essay on Astronomical and Meteorological Presages,* written in 1425. The illustration is thought to have been made by the Emperor himself. (See also page 9).

Photo © Cambridge University Library

Back cover: Chinese metallurgists practising their trade in the presence of the Emperor. Detail from a 19th-century book plate, Bibliothèque Nationale, Paris

Photo Jean-Loup Charmet © Photeb Archives, Bibliothèque Nationale, Paris

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editorial

The origins of many of the things the modern world takes for granted—from paper to porcelain, from mechanical clocks to the harness, steel-making and the extraction of petroleum and natural gas—can be traced to ancient China. Although for centuries these and many other achievements of Chinese inventiveness were forgotten or veiled in obscurity, in recent years the nature of the Chinese scientific genius has become increasingly appreciated. This is largely due to one of the outstanding intellectual ventures of our time, the research and writings of Dr. Joseph Needham of Cambridge University, who has spent over half a century investigating the history of Chinese science and technology. The results of Dr. Needham's investigations, and those of his colleagues at the Needham Research Institute in Cambridge, are being published in a monumental work, *Science and Civilisation in China,* which will be complete in 25 volumes. (Fifteen have so far appeared or are passing through the press.)

With Dr. Needham's authorization, an American science writer, Robert K.G. Temple, has written a book entitled *China, Land of Discovery and Invention* which attempts to make this scholarly research accessible to the general reader. All the articles in this issue have been extracted from Mr. Temple's book, with the kind permission of the publishers. The issue falls into 3 parts: a brief introduction in which Temple describes the genesis and importance of Needham's work; a short text in which Needham sets the question of scientific and technological activity in a social and economic context; and descriptions of over 20 discoveries and inventions. (Most of the descriptions have been abridged.) A celebration of the Chinese scientific genius, this issue may also lead readers to speculate about the surprises that will be revealed when the history of science and technology in other great world civilizations comes to be written.

The Chinese scientific genius

BY ROBERT K. G. TEMPLE

POSSIBLY more than half of the basic inventions and discoveries upon which the "modern world" rests come from China.

Without the importation from China of nautical and navigational improvements such as ships' rudders, the compass and multiple masts, the great European Voyages of Discovery could never have been undertaken. Columbus would not have sailed to America, and Europeans would never have established colonial empires.

Without the importation from China of the stirrup, to enable them to stay on horseback, knights of old would never have ridden in their shining armour to aid damsels in distress; there would have been no Age of Chivalry. And without the importation from China of guns and gunpowder, the knights would not have been knocked from their horses by bullets which pierced the armour, bringing the Age of Chivalry to an end.

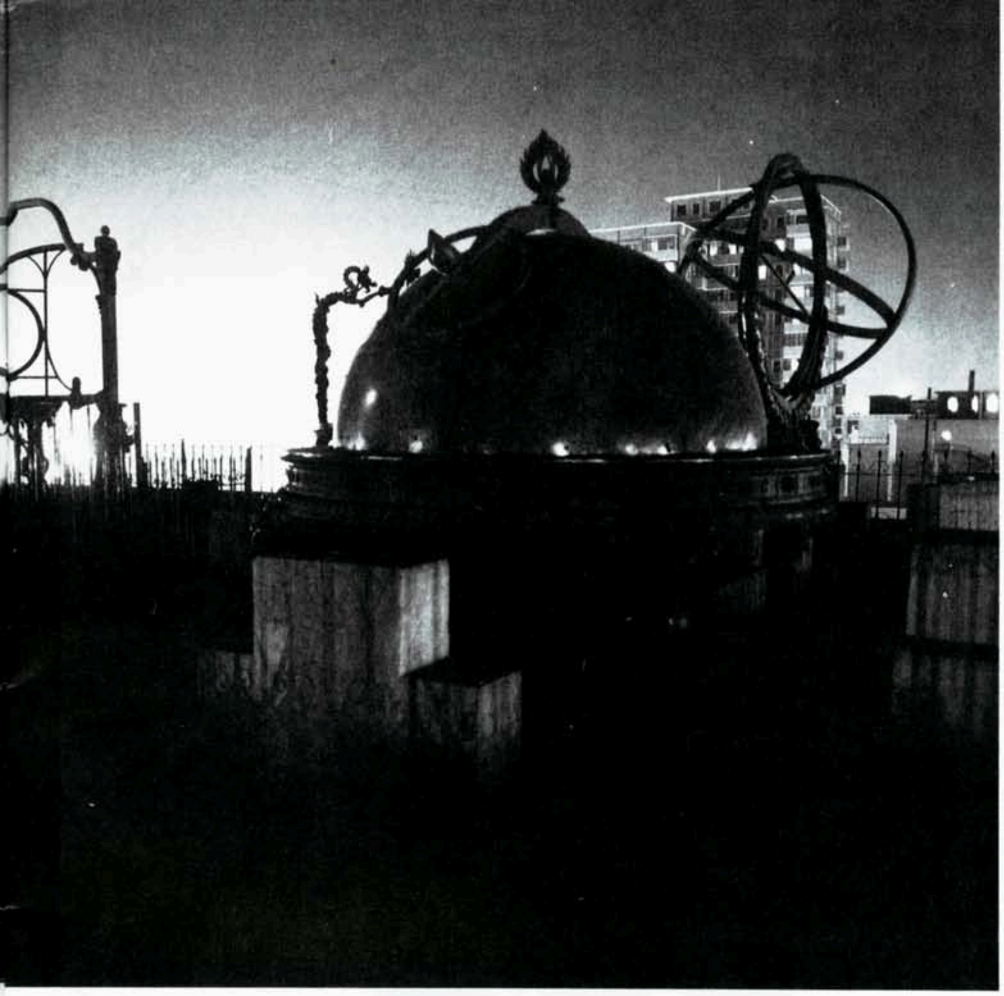
Without the importation from China of paper and printing, Europe would have continued for much longer to copy books by hand. Literacy would not have become so widespread.

Johann Gutenberg did *not* invent movable type. It was invented in China. William Harvey did *not* discover the circulation of the blood in the body. It was discovered—or rather, always assumed—in China. Isaac Newton was *not* the first to discover his First Law of Motion. It was discovered in China.

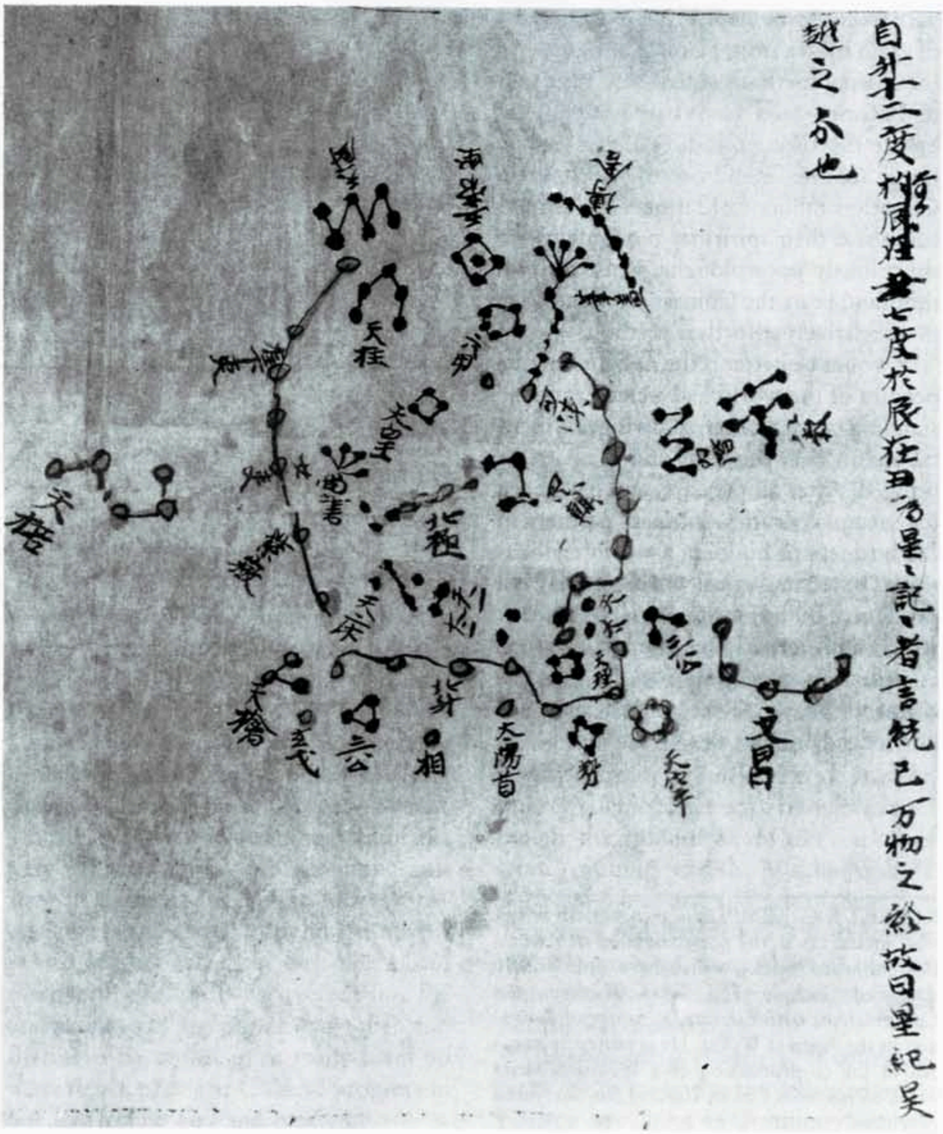
These myths and many others are shattered by our discovery of the true Chinese origins of many of the things, all around us, which we take for granted. It is exciting to realize that the East and the West are not as far apart in spirit or in fact as most of us have been led, by appearances, to believe, and that the East and the West *are already combined* in a synthesis so powerful and so profound that it is all-pervading. Within this synthesis we live our daily lives, and from it there is no escape. The modern world *is* a combination of Eastern and Western ingredients which are inextricably fused.

Right, detail from a Chinese star map dating from c. 940 AD. Some 1,350 stars are shown on the map. They are drawn in 3 colours, white, black and yellow, to correspond to 3 ancient schools of astronomy.

Left, hoeing crops during the Han Dynasty (207 BC-220 AD). Intensive hoeing and cultivation of crops in rows originated in China around the 6th century BC.



Astronomical instruments silhouetted against the sky at the Beijing Observatory, built in the 15th century. Beijing has had an astronomical observatory since the Qin Dynasty (3rd century BC).



The discovery of this truth is a result of incidents in the life of the distinguished British scholar Dr Joseph Needham, author of the great work *Science and Civilisation in China.* In 1937, aged thirty-seven, Needham was one of the youngest Fellows of the Royal Society and a biochemist of considerable distinction at Cambridge. He had already published many books, including the definitive history of embryology. One day he met and befriended some Chinese students, in particular a young woman from Nanjing named Lu Gwei-djen, whose father had passed on to her his unusually profound knowledge of the history of Chinese science. Needham began to hear tales of how the Chinese had been the true discoverers of this and that important thing, and at first he could not believe it. But as he looked further into it, evidence began to come to light from Chinese texts, hastily translated by his new friends for his benefit.

Needham became obsessed with this subject, as he freely admits. Not knowing a word of Chinese, he set about learning the language. In 1942 he was sent to China for several years as Scientific Counsellor to the British Embassy in Chongqing. He was able to travel all over China, learn the language thoroughly, meet men of science everywhere he went, and accumulate vast quantities of priceless ancient Chinese books on science. After the War, Needham became Unesco's first Assistant Director General for the natural sciences.

In July 1946 Needham stated in a lecture to the China Society in London that: "What is really very badly needed is a proper book on the history of science and technology in China, especially with reference to the social and economic background of Chinese life. Such a book would be by no means academic, but would have a wide bearing on the general history of thought and ideas."

Needham, now back in Cambridge, went ahead and wrote—and is still writing—the very work which he envisaged, except for the fact that it is, indeed, very academic. It is in fact much easier to read than it looks, but of course is very expen-

The earliest surviving Chinese notations are records of divination incised over 3,000 years ago on "oracle bones" (tortoise shells or the shoulder blades of animals). Some oracle bones unearthed near Anyang are inscribed with astronomical and calendrical information such as the names of stars and data about solar and lunar eclipses. Left, two Anyang oracle bones bearing astronomical inscriptions.

sive, and even many libraries cannot afford it. Needham, however, has never lost his early vision of a work which was "by no means academic"; he has always wanted to make his work more accessible in every possible way. Therefore, when I approached him in 1984 with the suggestion that I write a popular book for the general reader based upon his half century's labours, he agreed more readily than at the time I could understand. It is now clear that this was a project which he had long envisaged, and which he felt he could no longer hope to accomplish himself.

In the 1946 lecture which was so prophetic of his future activities, Dr. Needham went on to say: "I personally believe that all Westerners, all people belonging to the Euro-American civilization, are subconsciously inclined to congratulate themselves, feeling with some self-satisfaction that, after all, it was Europe and its extension into the Americas which developed modern science and technology. In the same way I think that all my Asian friends are subconsciously inclined to a certain anxiety about this matter, because their civilization did not, in fact, develop modern science and technology."

We need to set this matter right, from both ends. And I can think of no better single case than the lesson to be drawn from the history of agriculture. We should take to heart the astonishing and disturbing fact that the European agricultural revolution, which laid the basis for the Industrial Revolution, came about only because of the importation of Chinese ideas and inventions. The growing of crops in rows, intensive hoeing of weeds, the "modern" seed drill, the iron plough, the moldboard to turn the ploughed soil, and efficient harnesses were all imported from China. Before the arrival from China of the trace harness and the collar harness, Westerners choked their horses with straps round their throats.

Although ancient Italy could produce plenty of grain, it could not be transported overland to Rome for lack of satisfactory harnesses. Rome depended on shipments of grain by sea from places like Egypt. As for sowing methods—probably over half of Europe's seed was wasted every year before the Chinese idea of the seed drill came to the attention of Europeans. Countless millions of farmers broke their backs and their spirits by ploughing with ridiculously poor ploughs, while for two thousand years the Chinese were enjoying their relatively effortless method.

It would be better if the nations and the peoples of the world had a clearer understanding of each other, allowing the mental chasm between East and West to be bridged. After all they are, and have been for several centuries, intimate partners in the business of building a world civilization. The technological world of today is a product of both East and West to an extent which until recently no one had ever imagined. It is now time for the Chinese contribution to be recognized and acknowledged, by East and West alike. ■

ROBERT K.G. TEMPLE is an American writer who specializes in the popularization of science. His published works, which have been widely translated, include *The Sirius Mystery*, and *Conversations with Eternity*, a history of divination in the Ancient World. He is currently engaged in the co-production of a television series based on his book *China, Land of Discovery and Invention*.

Precursors

Left, a model reconstructed after a Tang Dynasty (7th century) original, of a "*li*-counter" or device for measuring distance. The counter was constructed in such a way that, as it moved along the road, one of the 2 drummers would beat the drum at each *li*, an ancient Chinese distance unit corresponding to half a kilometre.

# of modern science

BY JOSEPH NEEDHAM

THE extraordinary inventiveness, and insight into nature, of ancient and medieval China raises two fundamental questions. First, why should the Chinese have been so far in advance of other civilizations; and second, why aren't they now centuries ahead of the rest of the world? We think it was a matter of the very different social and economic systems in China and the West. Modern science arose only in Europe in the seventeenth century when the best method of discovery was itself discovered; but the discoveries and inventions made then and thereafter depended in so many cases on centuries of previous Chinese progress in science, technology and medicine.

The English philosopher Francis Bacon (1561-1626) selected three inventions, paper and printing, gunpowder, and the magnetic compass, which had done more, he thought, than any religious conviction, or any astrological influence, or any conqueror's achievements, to transform completely the modern world and mark it off from Antiquity and the Middle Ages. He regarded the origins of these inventions as "obscure and inglorious" and he died without ever knowing that all of them were Chinese. We have done our best to put this record straight.

Chauvinistic Westerners, of course, always try to minimize the indebtedness of Europe to China in Antiquity and the Middle Ages, but often the circumstantial evidence is compelling. For example the first blast furnaces for cast iron, now known to be Scandinavian of the late eighth century AD, are of closely similar form to those of the previous century in China; while as late as the seventeenth century all the magnetic compasses of surveyors and astronomers pointed south, not north, just as the compasses of China had always done. In many cases, however, we cannot as yet detect the capillary channels through which knowledge was conveyed from East to West. Nevertheless we have always adopted the very reasonable assumption that the longer the time elapsing between the appearance of a discovery or invention in one part of the world, and its appearance later on in some other part of the world far away, the less likely is it that the new thing was independently invented or discovered.

But all these things being agreed, a formidable question then presents itself. If the Chinese were so advanced in Antiquity and the Middle Ages, how was it that the Scientific Revolution, the coming of *modern* science into the world, happened only in Europe?

The fact is that in the seventeenth century we have to face a package deal; the Scientific Revolution was accompanied both by the Protestant Reformation and by the rise of capitalism, the ascendancy of the entrepreneurial bourgeoisie. Distinctively *modern* science, which then developed, was a mathematization of hypotheses about nature, combined with relentless experimentation. The sciences of all the ancient and medieval worlds had had an indelibly ethnic stamp, but now nature was addressed for the first time in a universal and international language, the precise and quantitative idiom of mathe-

This tower for measuring the shadow cast by the Sun at the winter and summer solstices was considered by Chinese astronomers in ancient times to be the centre of the world. A gnomon (sundial arm), almost 13 m high, stood upright in the central niche and its shadow was measured along the 40-metre-long horizontal stone scale (foreground). In its present form the structure is a Ming Dynasty (1368-1644) renovation of a building erected around 1276 AD.

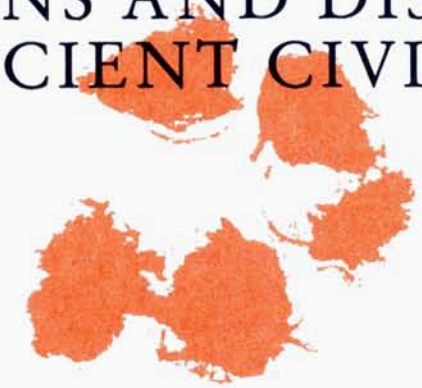
matics, a tongue which every man and woman, irrespective of colour, creed or race, can use and master if given the proper training. And to the technique of experiment the same applies. It was like the merchant's universal standard of value. How one looks at the primary causative factor in all this depends on one's own background. If one is a theologian one probably thinks that the liberation of the Reformation was responsible; if one is an old-fashioned scientist, one naturally thinks that the scientific movement occurred first and powered all the others; and if one is a Marxist, one certainly thinks that the economic and social changes bear the main responsibility.

One factor which must have great relevance here is the undeniable circumstance that the feudalism of Europe and China were fundamentally different. European feudalism was military-aristocratic: the peasantry were governed by the knights in their manors, and they in turn were subject to the barons in their castles, while the king in his palace ruled over all. In time of war he needed the help of the lower ranks in the feudal hierarchy who were bound to rally to him with stated numbers of men-at-arms. How different was the feudalism of China, long very justifiably described as bureaucratic. From the time of the first emperor, Qin Shih Huangdi, onwards (third century BC), the old hereditary feudal houses were gradually attacked and destroyed, while the king or emperor (as he soon became) governed by the aid of an enormous bureaucracy, a civil service unimaginable in extent and degree of organization to the petty kingdoms of Europe. Modern research is showing that the bureaucratic organization of China in its earlier stages strongly helped science to grow; only in its later ones did it forcibly inhibit further growth, and in particular prevented a breakthrough which has occurred in Europe. For example, no other country in the world at the beginning of the eighth century AD could have set up a meridian arc survey stretching from south to north some 4,000 kilometres. Nor could it have mounted an expedition at that time to go and observe the stars of the southern hemisphere to within 20° of the south celestial pole. Nor indeed would it have wanted to.

It may well be that a similar pattern will appear in the future when the history of science, technology and medicine, for all the great classical literary cultures, such as India or Sri Lanka, comes to be written and gathered in. Europe has entered into their inheritance, producing an ecumenical universal science and technology valid for every man and woman on the face of the Earth. One can only hope that the shortcomings of the distinctively European traditions in other matters will not debauch the non-European civilizations. For example, the sciences of China and of Islam never dreamed of divorcing science from ethics, but when at the Scientific Revolution the final cause of Aristotle was done away with, and ethics chased out of science, things became very different, and more menacing. This was good in so far as it clarified and discriminated between the great forms of human experience, but very bad and dangerous when it opened the way for evil men to use the great discoveries of modern science and divert them to activities disastrous for humanity. Science needs to be lived alongside religion, philosophy, history and aesthetic experience; alone it can lead to great harm. All we can do today is to hope and pray that the unbelievably dangerous powers of atomic weapons, which have been put into the hands of human beings by the development of modern science, will remain under control by responsible men, and that maniacs will not release powers that could extinguish not only mankind, but all life on Earth. ■

JOSEPH NEEDHAM, British historian of Chinese science and technology, is director of the Needham Research Institute in Cambridge, England. For more than 40 years he has been engaged on a monumental, multi-volume history of *Science and Civilisation in China* (Cambridge University Press), of which he is the director and principal contributor.

INVENTIONS AND DISCOVERIES OF AN ANCIENT CIVILIZATION



The observation of sunspots

Most of the sunspots seen in the West before the seventeenth century were explained away as transits of the Sun by the planets Mercury and Venus. The theory of "perfection of the Heavens" forbade the admission of any imperfections on the surface of the Sun.

The Chinese suffered from no such preconceived insistence on "perfection". Since sunspots are sometimes large enough to be seen by the naked eye, the Chinese naturally saw them. The earliest surviving record we have of their observations would seem to be some remarks by one of the three known early astronomers in China. He was Gan De, who lived in the fourth century BC. He and two contemporaries, Shi Shen and Wu Xian, drew up the first great star catalogues. Their work was fully comparable to that of the Greek Hipparchos, though two centuries earlier.

The next indication of a sunspot observation dates from 165 BC. We are told in a much later encyclopaedia, *The Ocean of Jade*, that in that year the Chinese character *wang* appeared in the Sun. This was therefore a sunspot which appeared not round, but shaped like a cross with a bar drawn across the top and the bottom. The astronomer D.J. Schove accepts this as the world's earliest precisely dated sunspot. The recording of sunspot observations in the voluminous official imperial histories of China commenced on 10 May 28 BC. But systematic Chinese observations of sunspots probably began at the latest by the fourth century BC, and only the loss of much literature of that time denies us more specific information.

Most people today believe that sunspots were first observed in the West by Galileo, who is also supposed to have been the first person to "invent" or at least use the telescope. Neither belief is true. Galileo most certainly did not invent the telescope, though he gave it prominence, and courageously advocated its use to study the heavens. As for the observation of sunspots, the earliest clear reference to them so far found in Western literature is in Einhard's *Life of Charlemagne*, of about 807 AD.

Later sunspot observations in the West were made by the Arab Abu al-Fadl Ja'far ibn al-Muqtafi in 840 AD, by Ibn Rushd about 1196, and by Italian observers around 1457.

Needham has counted the numbers of sunspot observations in the official histories between 28 BC and 1638 AD, and has found 112 instances. There are also hundreds of notices of sunspots in other Chinese books during the centuries. These Chinese records are the oldest and longest continuous series of such observations in the world. ■

The Editors wish to thank the organizers of a major exhibition on Chinese science and technology, "Chine Ciel et Terre, 5000 Ans d'Inventions et de Découvertes", for their help in the preparation of this issue. The exhibition is being held at the Musées Royaux d'Art et d'Histoire in Brussels from 16 September 1988 to 16 January 1989.

Cast iron

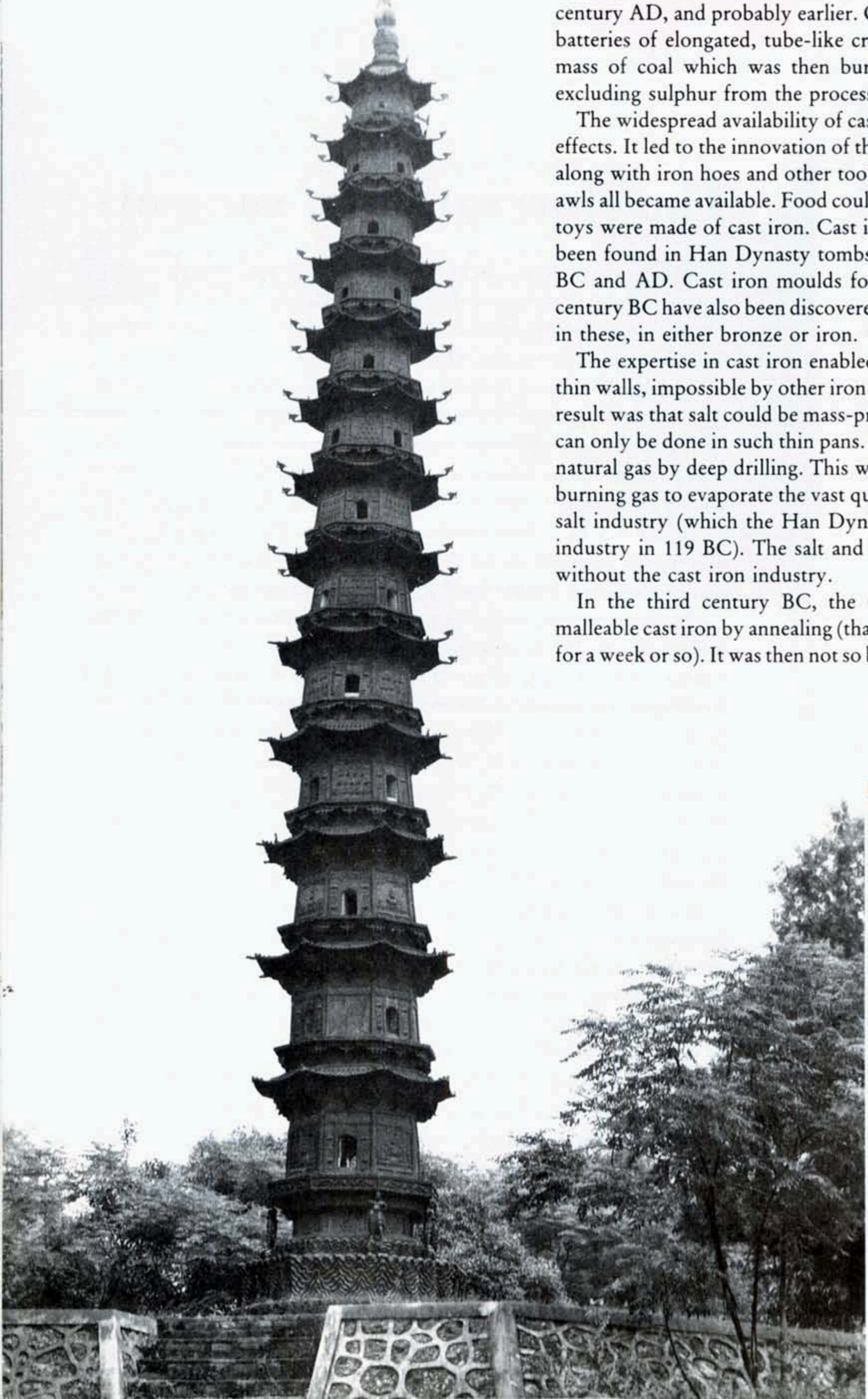
The Chinese practised the technique of using blast furnaces for making cast iron from at least the fourth century BC. There were a number of reasons for this. China had good refractory clays for the construction of the walls of blast furnaces. The Chinese also knew how to reduce the temperature at which the iron would melt. They threw in something which they called "black earth", which contained much iron phosphate. If up to 6 per cent of phosphorus is added in this way to an iron mixture, it reduces the melting point from the normal 1130°C to 950°C. This technique was used in the early centuries, ceasing before the sixth century AD, when proper blast furnaces came into use which needed no such assistance.

Coal, which gave a high temperature, was used as a fuel from the fourth century AD, and probably earlier. One method was to put the iron ore in batteries of elongated, tube-like crucibles, and pack these round with a mass of coal which was then burnt. This had the extra advantage of excluding sulphur from the process.

The widespread availability of cast iron in ancient China had many side effects. It led to the innovation of the cast iron ploughshare in agriculture, along with iron hoes and other tools. Iron knives, axes, chisels, saws and awls all became available. Food could be cooked in cast iron pots, and even toys were made of cast iron. Cast iron statuettes of various animals have been found in Han Dynasty tombs dating between the second centuries BC and AD. Cast iron moulds for implements dating from the fourth century BC have also been discovered. Hoes and axes would have been cast in these, in either bronze or iron.

The expertise in cast iron enabled pots and pans to be made with very thin walls, impossible by other iron technology. One extremely important result was that salt could be mass-produced from evaporated brine, which can only be done in such thin pans. This in turn led the Chinese to exploit natural gas by deep drilling. This was in order to tap the energy from the burning gas to evaporate the vast quantities of brine required for the giant salt industry (which the Han Dynasty nationalized along with the iron industry in 119 BC). The salt and gas industries could not have existed without the cast iron industry.

In the third century BC, the Chinese discovered how to make a malleable cast iron by annealing (that is, by holding it at a high temperature for a week or so). It was then not so brittle, and would therefore not shatter



Towering achievement of early Chinese metallurgy. The 13-m-high Yu Quan pagoda at Dangyang (Hubei) is entirely built of cast iron. Erected in 1061, it is the oldest surviving cast iron pagoda.

if subjected to a violent shock. This meant that objects like ploughshares could survive striking large stones with considerable force. Cast iron had something of the elasticity of wrought iron, but with the much greater strength and solidity that came from being cast. It was almost as good as steel.

Some of the ancient Chinese feats of casting iron are so impressive as to be almost unbelievable, even when the results are before our eyes. For instance, there is the cast iron pagoda shown on opposite page.

Perhaps the grandest cast iron structure of all was not actually a building. The Empress Wu Zetian had an octagonal cast iron column built, called the "Celestial Axis Commemorating the Virtue of the Great Zhou Dynasty with Its Myriad Regions". It was built in 695 AD upon a base of cast iron 51 metres in circumference and 6 metres high. The column itself was 3.6 metres in diameter and rose 32 metres in the air; on top was a "cloud canopy" 3 metres high and 9 metres in circumference. On top of this in turn stood four bronze dragons each 3.6 metres high supporting a gilded pearl. We have a record of the amount of metal used in this construction—about 1,325 tons. The largest single cast iron object ever made (the pagodas were obviously not a single piece) was erected on the orders of the Emperor Shizong of the Later Zhou Dynasty in commemoration of his campaign against the Tartars in 954 AD. This extraordinary object, 6 metres tall, still stands and is known as the Great Lion of Zangzhou (Hebei). It is not solid, but its walls vary from 4 to 20 centimetres. in thickness. ■

Tibetan brass globe lamp. The lamp is suspended by 4 separate interlocking rings which ensure that it always remains upright.

The cardan suspension

The "cardan suspension", or gimbals, takes its name from Jerome Cardan (Girolamo Cardano, 1501-1576). But Cardan neither invented the device nor claimed to have done so. He merely described it in his very popular book *De subtilitate rerum* (1550; "The Subtlety of Things"). It appeared in Europe as early as the ninth century AD; but it was invented in China by the second century BC at the latest.

This invention is the basis of the modern gyroscope, making possible the navigation and "automatic pilots" taken for granted in modern aircraft. Anyone who has been fortunate enough to enter a nineteenth-century Gypsy caravan will have noticed affixed to the walls the brass gimbals that hold lamps which remain upright no matter how violently the cart may jolt on the road. These interlocking brass rings can be moved around as much as you like, but the lamp suspended in the centre never turns over. This is the basic idea of the "cardan suspension". A series of rings inside one another are each joined at two opposing points, enabling them to twist and turn freely. Consequently, if a heavy weight, such as a lamp, is positioned upright in the centre, it will remain upright. Whatever motions might occur to the rings around it will be taken up by the rings themselves, leaving the lamp unmoved. By the eighteenth century, Chinese mariners were using a gimbal-mounted compass. A ship's magnetic compass mounted in this way was free of disturbance by waves.

The earliest textual reference to gimbals which has been found is in a poem called *Ode on Beautiful Women,* composed about 140 BC. More than three centuries later, about 189 AD, the clever mechanic Ding Huan was given credit for inventing gimbals a second time.

Gimbals reached Europe after 1,100 years. And 800 years after that, the English physicist Robert Hooke and others adopted its principle in a new form, applying power from without rather than stabilizing a central element within, to formulate that Western invention, the universal joint. And it was this invention which resulted in the transmission of automotive power in contemporary motor cars. ■

Steel manufacture

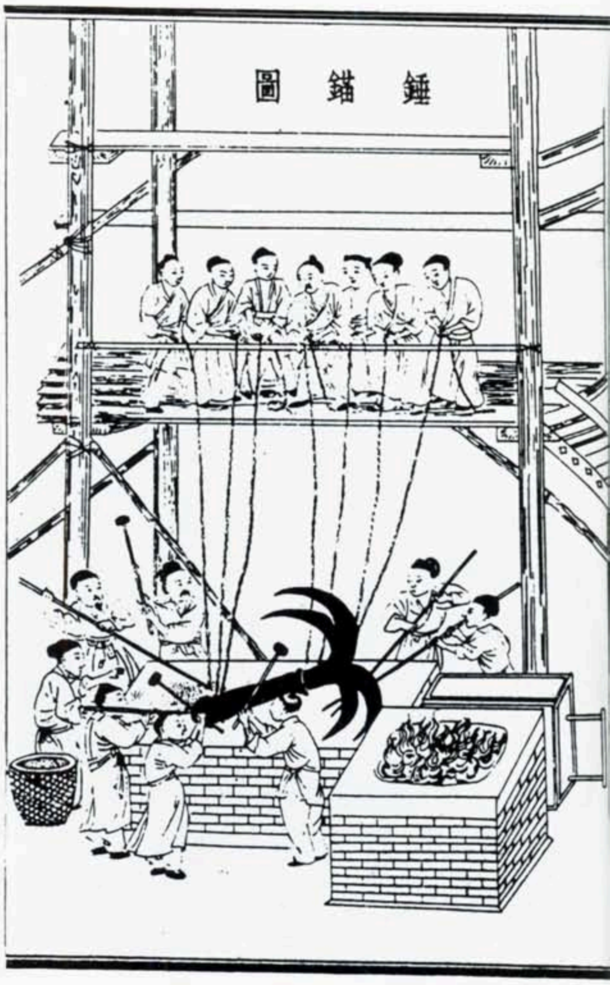
The Chinese were the first to produce cast iron, and were also the first to make steel from cast iron. This was fully under way by the second century BC at the latest, and eventually led to the invention of the Bessemer steel process in the West in 1856. Henry Bessemer's work had been anticipated in 1852 by William Kelly, from a small town near Eddyville, Kentucky. Kelly had brought four Chinese steel experts to Kentucky in 1845, from whom he had learned the principles of steel production used in China for over 2,000 years previously, and had made his own developments.

Iron, when melted and reformed into ingots, has a carbon content. This determines the nature of the metal as cast iron or steel, whichever the case may be. Cast iron is brittle because it contains a considerable quantity of carbon, perhaps as much as 4.5 per cent. "Decarburization" is the removal of some or all of this carbon. Remove much of the carbon and you have steel; remove nearly all the carbon and you have wrought iron. The Chinese used wrought iron a great deal, most notably perhaps in building large bridges and aqueducts.

The Chinese invented the suspension bridge, often constructing such bridges with chains whose links were of wrought iron instead of plaited bamboo. Cast iron was called "raw iron", steel was called "great iron", and wrought iron was called "ripe iron" by the Chinese. In order to make iron "ripe", they clearly understood that the iron was losing a key ingredient, and they described this as "loss of vital juices". But, without knowledge of modern chemistry, they could not identify the ingredient as carbon.

The Chinese were not the first to make steel. But they did invent two particular steel manufacturing processes, of which taking the carbon out of cast iron was the first. The process of "decarburization" was accomplished by blowing oxygen on to the cast iron ("oxygenation"). We read of this in the classic *Huainanzi,* which dates from about 120 BC.

Making steel by this method was also called "the hundred refinings method", since it was often done over and over again, the steel becoming stronger each time. Swords made by this method were highly prized. The back of the sword, not having an edge, would often be made of the more elastic wrought iron, and the harder steel would be welded on to it to bear the cutting edge for a sabre. The carbon content of the steel could be adjusted depending upon how much oxygen was applied to the molten iron.



Chinese 17th-century print showing artisans forging an anchor weighing several tons.

Generally speaking, steel with a higher carbon content is stronger, but then strength is traded against brittleness. Steel can have a carbon content of between 0.1 per cent and 1.8 per cent. The Chinese could only make empirical judgments on the qualities of steel obtained from certain numbers of refinings. If very soft steel was desired, they could go on blowing more oxygen in, removing increasing amounts of the carbon. And they practised the world-wide technique of quenching, whereby steel that is cooled instantly in a liquid when still either red- or white-hot preserves its inner metallic micro-structure which it would lose if allowed to cool slowly. On the other hand, cooling steel slowly (tempering) has other advantages. The Chinese were great masters at manipulating their iron materials in countless different ways to obtain the exact type of metal they required.

Around the fifth century AD, the Chinese developed the "co-fusion" process, in which cast and wrought iron were melted together to yield the "something in between", which was steel. This is essentially the Martin and Siemens steel process of 1863, though carried out 1,400 years earlier.

The process was in full swing by the sixth century, from which time we have a Chinese description of it: "Qiu Huaiwen also made sabres of 'overnight iron'. The method was to bake the purest cast iron, piling it up with the soft ingots of wrought iron, until after several days and nights, it was all turned to steel."

We are given precise technical details by Song Yingxing in 1637:

"The method of making steel is as follows. The wrought iron is beaten into thin plates or scales as wide as a finger and around four centimetres long. These are packed within wrought iron sheets and all tightly pressed down by cast iron pieces piled on top. The whole furnace is then covered over with mud (or clay) as well. Large furnace piston bellows are then set to work, and when the fire has risen to a sufficient heat, the cast iron comes to its transformation [i.e. melts] first, and dripping and soaking, penetrates into the wrought iron. When the two are united with each other, they are taken out and forged; afterwards they are again heated and hammered. This is many times repeated."

In our own time, experiments have been carried out at the steel works at Corby in the UK to reproduce the ancient Chinese steel-making techniques. The experiments were thoroughly successful. A very uniform steel was obtained, with the carbon from the cast iron spread very evenly throughout, and a genuine blending of the cast and wrought iron. The original heating went up to 975°C, and the metal was taken out and forged with a hand hammer. It was then heated for eight hours at 900°C and came out beautifully. ■

The chain pump

One of the inventions of the greatest utility which has spread from China throughout the world, so that its origins are no longer realized, is the square-pallet chain pump. It consists of an endless circulating chain bearing square pallets which hold water, earth, or sand.

This pump can haul enormous quantities of water from lower to higher levels. The optimum angle of slope at which the chain of pallets can be laid out is about 24°. So, depending on how well the pallets were fitted to avoid leakage and on the sturdiness of the machine as a whole, the height that water can be raised by a single pump is about 5 metres.

By medieval times in China, the pumps had been adapted for use as conveyors of earth or sand rather than just water. They were thus the first conveyor belts.

We do not know who invented the chain pump, or exactly when. Although it may have existed some centuries earlier, we can take as its time of origin the first century AD. The philosopher Wang Chong refers to its existence about 80 AD in his book *Discourses Weighed in the Balance*. Considerable improvements were made to the design during the next century. We know this from an account in the imperial history of the time, which discusses the lack of water in the capital, Luoyang. The history tells us that the famous eunuch minister Zhang Rang (died 189 AD) ordered various improvements for Luoyang from the engineer Bi Lan:

"He further asked Bi Lan ... to construct square-pallet chain pumps and suction pumps, which were set up to the west of the bridge outside the Peace Gate to spray water along the north-south roads of the city, thus saving the expense incurred by the common people [in sprinkling water on these roads and carrying water to the people living along them] ...

Chain pumps had achieved a standard form in China by 828. The imperial history for that year records:

"In the second year of the Taihe reign-period, in the second month ... a standard model of the chain-pump was issued from the palace, and the people of Jingzhao Fu were ordered by the Emperor to make a considerable number of the machines, for distribution along the Zheng Bai Canal, for irrigation purposes."

The pumps were used for civil engineering works and for draining all sorts of sites, as well as for irrigation and the supply of drinking water. The pumps were so spectacular in their results that visiting dignitaries and ambassadors from neighbouring lands eventually adopted them in their own countries. ■

Raising water for irrigation in 17th-century China, using a two-man treadle-operated chain pump.

A cybernetic machine

By the third century AD at the latest, the Chinese had a fully operational, navigational "cybernetic machine", using the principles of feedback. It was called the "south-pointing carriage", but had no connection with a magnetic compass. It was a large carriage, 3.3 metres long, 3.3 metres deep, and 2.75 metres wide, surmounted by a jade statue of an "immortal"—a sage who had achieved immortality. The figure's arm was raised, pointing ahead, and it always faced towards the south, no matter which way the carriage turned. Even if the road were circular, the jade figure would rotate, keeping the finger pointing in the same direction. How was this possible in the third century AD? This machine may have been invented even earlier, indeed, as much as 1,200 years earlier. An official history for 500 AD describes how:

"The south-pointing carriage was first constructed by the Duke of Zhou [beginning of the first millennium BC] as a means of conducting homewards certain envoys who had arrived from a great distance beyond the frontiers. The country was a boundless plain in which people lost their bearings as to east and west, so the Duke caused this vehicle to be made in order that the ambassadors should be able to distinguish north and south."

If this information is correct, the invention would date from about 1030 BC. But Needham suspects that the word "carriage" was inserted in this account by scribes, and that what is being described is a "south-pointer", that is, a compass.

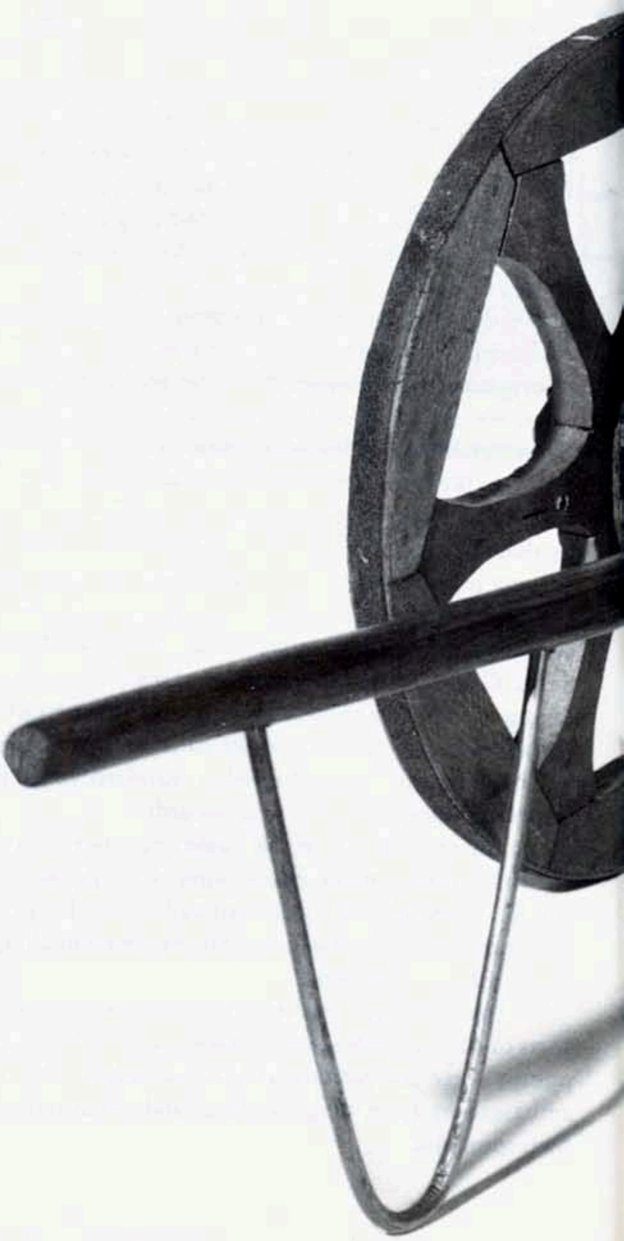
The next person credited with building a south-pointing carriage is the astronomer and scientist Zhang Heng, about 120 AD, although this is also regarded by Needham as doubtful. The only date which he is prepared to accept with certainty is the middle of the third century AD, with the famous engineer Ma Jun as the builder (and, thus, the inventor). The drawing of a pointing figure of jade, taken from the *Universal Encyclopaedia* of 1601, was copied from a print of 1341.

If the machine did not use a magnetic compass, how did it work? The answer is that it had a train of differential gears, similar to those in a modern automobile. Perhaps the function of a differential gear should be explained as follows. When a wheeled vehicle is turning a corner the wheels on opposite sides of the vehicle are clearly going to need to turn at different rates since the near side is travelling a shorter distance than the far side. With a hand-cart or horse-drawn carriage, this may not pose such problems. But when a vehicle has power being applied to the axle to make the wheels turn, how is it possible for one wheel to be permitted to speed up a little, and the other slow down a little, on the same axle? This is made possible only by an ingenious combination of gear wheels and flywheels: the differential gear.

When Needham published his volume on mechanical engineering in 1965, he believed that the Chinese had invented the differential gear, and that it had made its first appearance in this south-pointing carriage. If the first south-pointing carriage were the one attributed to the Duke of Zhou about 1000 BC, then the Chinese would indeed have been the inventors; but we must stay on the side of caution, and assume that the first south-pointing carriage was made in the second or third century AD. In that case, we must credit the Greeks with inventing the differential gear, a fact which became known only in 1975, when Professor Derek Price published his book *Gears from the Greeks.* In this work Price wrote the definitive account of a Greek differential gear dating from 80 BC, which Price said "must surely rank as one of the greatest basic mechanical inventions of all time". And although a transmission of this invention from Greece and Rome to China was possible, it is equally possible that the differential gear was independently re-invented in China for the south-pointing carriage.

The precision needed in the construction of the south-pointing carriage almost defies belief. For the outside road wheels alone, Needham points out, J. Coales, in *The Historical and Scientific Background of Automation,* "has calculated that a difference of only one per cent between the wheel circumferences would lead to a change of direction of the pointing figure of as much as 90 per cent in a distance only fifty times that between the two

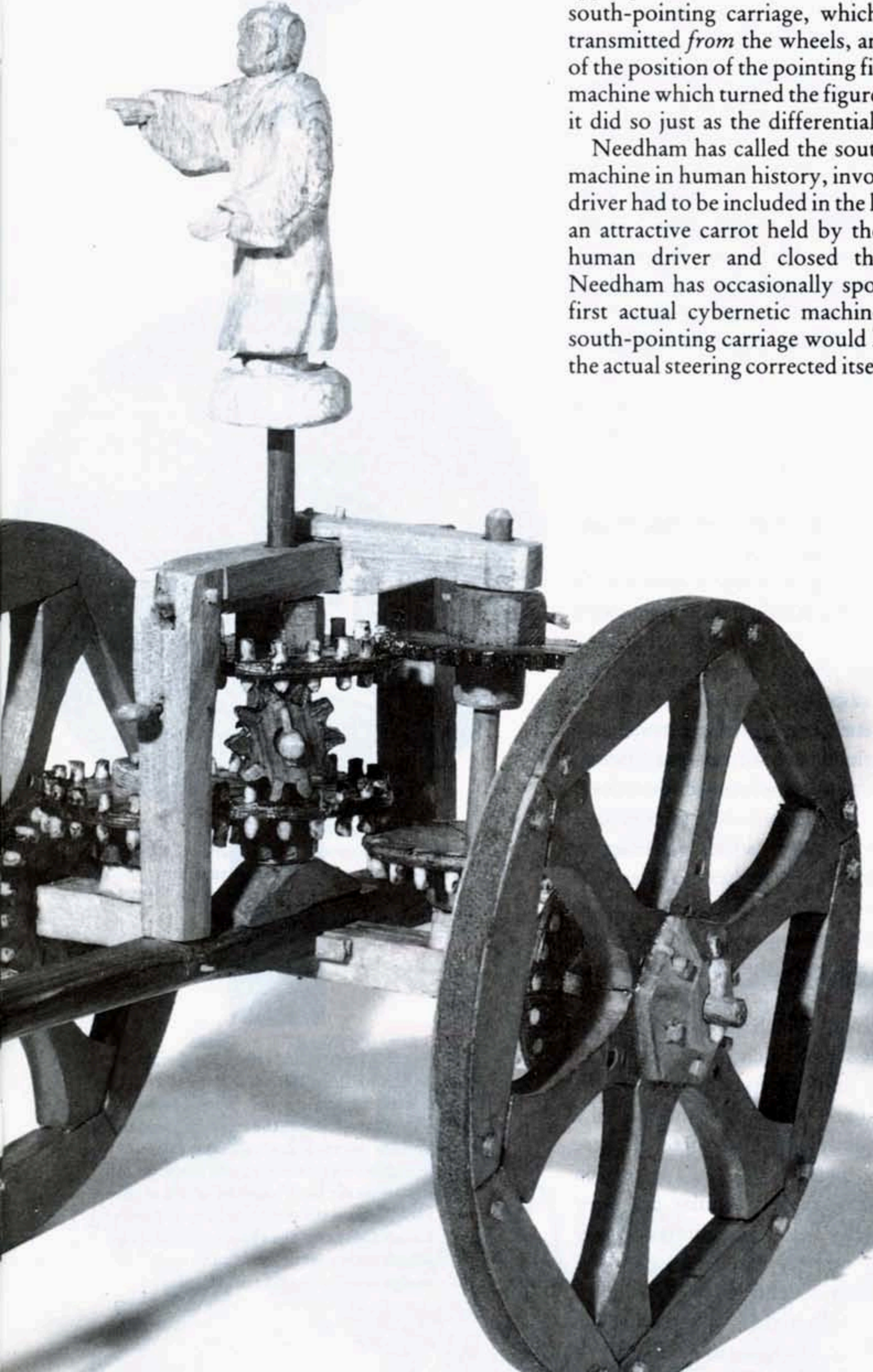
Model reconstruction of a "south-pointing carriage" based on a description dating from the 3rd century AD. Owing to a sophisticated gearing system, the figure's arm always points southwards, whatever the direction in which the carriage is moving.



wheels." This was because the carriage would veer more and more to one side if one wheel were smaller (relative slip). So that for this south-pointing carriage, the size of the road wheels had to be accurate to a margin of error far less than one per cent, and a commensurate accuracy in size of gear wheels would have been necessary. This points to engineering of such a high order that we may well be justified in hesitating to apply the words "ancient" and "primitive" to it!

The south-pointing device was basically a reversal of the use of the differential gear in the modern automobile. Today, such gears are used to apply power to turn the wheels and make the vehicle move. But with the south-pointing carriage, which was pulled by animals, the power was transmitted *from* the wheels, and applied towards the continual adjusting of the position of the pointing figure. Thus it was the differential gear in the machine which turned the figure so that it always pointed to the south. And it did so just as the differential gear operates today, only in reverse.

Needham has called the south-pointing carriage "the first homeostatic machine in human history, involving full negative feedback. Of course, the driver had to be included in the loop. But as Coales has acutely pointed out, an attractive carrot held by the pointing figure might have replaced the human driver and closed the loop more automatically." Although Needham has occasionally spoken of the south-pointing carriage as the first actual cybernetic machine, he has qualified this by saying: "The south-pointing carriage would have been the first cybernetic machine had the actual steering corrected itself, as we could easily make it do today." ■



'Magic mirrors'

Those who like to think of China as a land of mystery are well served by the Chinese "magic mirrors", which are some of the strangest objects in the world. They are known to go back to at least the fifth century AD, though their exact origins are unknown. About 1,200 years ago, there still existed a book entitled *Record of Ancient Mirrors,* which apparently contained the secrets of these magic mirrors and their construction, but sadly it seems to have been lost for over a thousand years.

When magic mirrors came to the attention of the West in 1832, dozens of prominent scientists attempted to discover their secret. It was a hundred years before a satisfactory theory of magic mirrors was formulated by the British crystallographer Sir William Bragg.

What exactly, then, is a magic mirror? On its back it has cast bronze designs—pictures, or written characters, or both. The reflecting side is convex and is of bright, shiny polished bronze which serves as a mirror. In many conditions of lighting, when held in the hand, it appears to be a perfectly normal mirror.

However, when the mirror is held in bright sunshine, its reflecting surface can be "seen through", making it possible to inspect from a reflection cast on to a dark wall the written characters or patterns on the back. Somehow, mysteriously, the solid bronze becomes transparent, leading to the Chinese name for the objects, "light-penetration mirrors".

But surely, the reader will protest, solid bronze cannot be transparent. This is true, and there was certainly a trick to it. But it was a sufficiently good trick to baffle Western scientists for a century, and even the earliest surviving Chinese discussion of magic mirrors consists of speculation on how they might work. This occurs in a fascinating work, *Dream Pool Essays,* by Shen Gua, published in 1086. Even at this date, Shen Gua thought of the mirrors as coming from some vague archaic period:

"There exist certain 'light-penetration mirrors' which have about twenty characters inscribed on them in an ancient style which cannot be interpreted. If such a mirror is exposed to the sunshine, although the characters are all on the back, they 'pass through' and are reflected on the wall of a house, where they can be read most distinctly.... I have three of these inscribed 'light-penetration mirrors' in my own family, and I have seen others treasured in other families, which are closely similar and very ancient; all of them 'let the light through'. But I do not understand why other mirrors, though extremely thin, do not 'let light through'. The ancients must indeed have had some special art .... Those who discuss the reason say that at the time the mirror was cast, the thinner part became cold first, while the raised part of the design on the back, being thicker, became cold later, so that the bronze formed minute wrinkles. Thus although the characters are on the back, the face has faint lines too faint to be seen with the naked eye."

Although differences of cooling rate are not the explanation, Shen Gua was correct in suggesting that the shiny, polished mirror surfaces concealed

Above, the polished reflecting surface and (top) the ornamented back of a bronze "magic mirror". When bright light is projected at the reflecting surface and the mirror is held so that it casts a reflection on a dark wall, the ornamental design on the back becomes visible in the reflection on the wall. The mirror shown here is Japanese. The characters *Takasago* which form part of the ornamental design refer to the title of a *No* play.

minute variations which the eye alone could not detect. Needham says of the experiments carried out by European scientists: "Careful and extended optical experimentation demonstrated that the surfaces of 'magic' mirrors reproduced the designs on the backs because of very slight inequalities of curvature, the thicker portions being very slightly flatter than the thinner ones, and even sometimes actually concave."

The basic mirror shape, with the design on the back, was cast flat, and the convexity of the surface produced afterwards by elaborate scraping and scratching. The surface was then polished to become shiny. The stresses set up by these processes caused the thinner parts of the surface to bulge outwards and become more convex than the thicker portions. Finally, a mercury amalgam was laid over the surface; this created further stresses and preferential buckling. The result was that imperfections of the mirror surface matched the patterns on the back, although they were too minute to be seen by the eye. But when the mirror reflected bright sunlight against a wall, with the resultant magnification of the whole image, the effect was to reproduce the patterns *as if* they were passing through the solid bronze by way of light beams. As Sir William Bragg said when he finally discovered this in 1932: "Only the magnifying effect of reflection makes them plain." Needham rightly calls this "the first step on the road to knowledge about the minute structure of metal surfaces." ■

Efficient horse harnesses

From earliest times until the eighth century AD in the West (and, as we shall see, much earlier in China), the only means of harnessing horses was by the "throat-and-girth harness". It was an absurd method since the strap across the throat meant that the horse was choked as soon as he exerted himself. As long as man was restricted to the use of this pathetic harness, horsepower was all but useless for transport by cart. Even individual riders could half-strangle their mounts at a gallop.

Those who read about ancient Rome are often struck by the importance attached to the shipping of grain from Egypt. Without Egyptian grain, Rome must starve. But why? What was wrong with grain grown in Italy,

A Han Dynasty rubbing (c. 1st century BC) showing the use of the trace harness, with its breast strap, to pull a carriage whose passengers are protected from the elements by a precursor of the umbrella.

one asks? Why was Rome dependent on ships from Egypt in order to be able to eat? The answer is simply that there was no horse harness capable of making it possible for Italian grain to be transported to Rome.

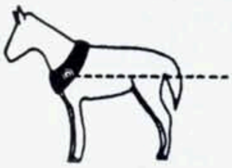
In about the fourth century BC the Chinese made a great breakthrough. A lacquered box of the period bears a painting which shows a yoke across the horse's chest, from which traces connect it to the chariot shafts. Soon, the hard yoke across the breast was also abandoned and replaced by the more satisfactory breast strap, commonly called the "trace harness". There is no longer a strap across the horse's throat; the weight of the load is borne by the horse's chest and collar bones.

Experiments have been carried out to establish the relative efficiency of the different types of harness. Two horses harnessed in the throat-and-girth fashion can pull a load of half a ton. But a single horse in a collar harness (described below) can easily pull a ton and a half. With a trace harness the efficiency is only slightly less.

Needham suggests two factors which may have led the Chinese to invent the trace harness. There was the motivation of the Chinese, Mongols and Huns living on the edge of the Gobi Desert where they were always getting stuck in the sand, from which horses using the throat-and-girth harness could not extricate them. Secondly, there was the use of human hauliers. Man's own experience of hauling, for example, boats upstream, meant that he was quickly aware of the inadequacy of a rope round the neck.

The most efficient harness is the collar harness (see drawing this page). The earliest evidence for the collar harness in China may be seen in a rubbing from an ancient brick. It dates from some time between the fourth and first centuries BC. Therefore, we must consider the collar harness as having been invented in China by the first century BC at the latest. This is a full thousand years before its appearance in Europe a century after the trace harness.

After some time, it was found by the Chinese that the collar could be used in another and simpler way: traces could be attached from the sides of the collar directly to the vehicle. It is this form of the collar harness which is used today all round the world. ■



Collar harness

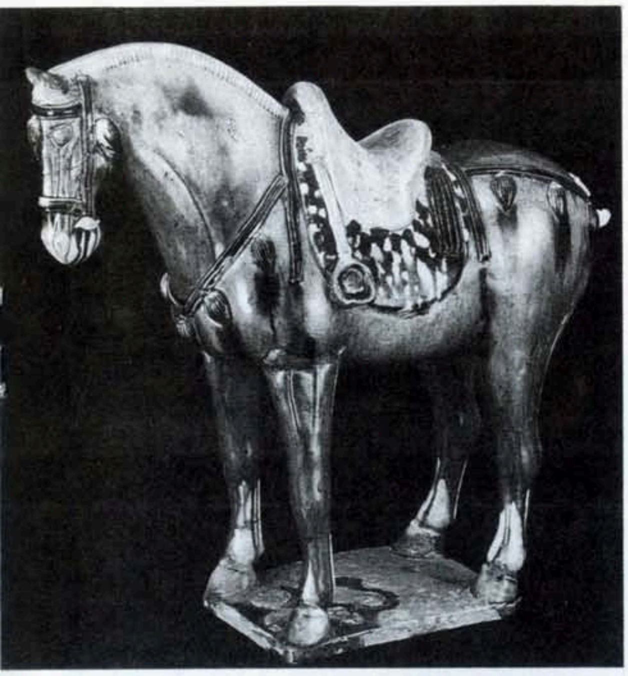
The stirrup

For most of the time that man has been riding horses, he has had no supports for his feet. Stirrups were unknown to most of the great armies of ancient times—the Persians and Medes, the Romans, the Assyrians, the Egyptians, the Babylonians, the Greeks. The horsemen of Alexander the Great made their way across the whole of Central Asia without being able to rest their feet while in the saddle. When galloping or jumping, horsemen had to hold the horse's mane tightly to avoid falling off. The Romans devised a kind of hand-hold on the front of the saddle which gave them something of a grip when the going got rough; but their legs just dangled whenever they were not pressed tightly against the horse.

Mounting a horse without stirrups was not so easy either. Fierce warriors took pride in their flying leaps, gripping the mane with the left hand and swinging themselves up; and some bareback riders still do this today. Cavalrymen of ancient times used their spears to help them up, either by hoisting themselves aloft as in pole-vaulting, or by using a peg sticking out of the spear as a footrest. Otherwise it was necessary to rely on a groom for a leg-up.

By about the third century AD, the Chinese had remedied this situation. With their advanced metallurgical expertise they began to produce cast

Bronze stirrup dating from the 6th or 7th century AD



Tang Dynasty (618-907 AD) porcelain horse, harnessed for riding.

Bronze bit from a horse's bridle, China, 5th century BC

bronze or iron foot stirrups. No inventor of the stirrup is recorded and the original idea probably came from the occasional use of a loop of rope or leather to assist in mounting. Of course, such loops could not be used for riding, because if one fell off, one would be dragged along and come to a sticky end. Such loops may have been first used by the Chinese, the Indians, or the nomads of Central Asia bordering on China. The essentials of the stirrup may thus have originated in the steppes, the product of ingenious men whose lives were lived on horseback. Apparently from the third century, the Chinese were casting perfect metal stirrups. The earliest surviving depiction of a stirrup is on a pottery figure of a cavalryman found in a tomb in Changsha (Hunan) and dated to 302 AD.

The transmission of stirrups westward took place with the migrations of a fierce tribe called the Ruan-Ruan, who came to be known as the Avars. Their cavalry was devastatingly effective because they had the use of cast-iron stirrups. About the middle of the sixth century, they were driven westwards and moved across south Russia to settle between the Danube and the Theiss. By 560, the Avars were a serious threat to the Byzantine Empire, and the Byzantine cavalry was entirely reorganized in order to counter them. The Emperor Maurice Tiberius prepared a military manual, the *Strategikon*, in 580, specifying the cavalry techniques to be adopted. He mentions the need to use iron stirrups—the earliest mention in European literature.

Stirrups then spread to the rest of Europe by means of the Vikings and possibly the Lombards. One Avar-style child's stirrup has even been excavated in London, brought by a Viking. But the use of stirrups in Europe (other than by the Byzantines and the Vikings) was long delayed, for reasons which are not entirely clear. Conventional armies of Europe do not seem to have adopted them until the early Middle Ages. Perhaps the lack of metallurgical expertise was a handicap, with stirrups having to be of wrought rather than cast metal for a long time. Mass production of stirrups was only possible with cast metal. ■

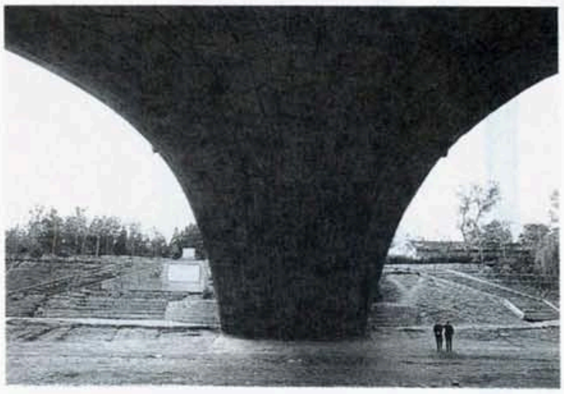
The segmental arch bridge

A conceptual breakthrough occurred when a Chinese engineer realized that an arch did not have to be a semi-circle. A bridge could be built which was based not on the traditional semi-circular arch but on what is known as a segmental arch. The way to envisage this is to imagine a gigantic circle embedded in the ground, of which only the tip shows above ground level. This tip is a segment of a circle, and the arch it forms is a segmental arch. Bridges built in this way take less material and are stronger than ones built as semi-circular arches.

This advance took place in China in the seventh century AD. It was the concept of Li Chun, the founder of an entire school of constructional engineering whose influence lasted for many centuries. We are fortunate that his first great bridge, built in 610, survives intact and is still very much in use today. Called the Great Stone Bridge, it spans the Jiao river near Zhaoxian at the foot of the Shanxi Mountains on the edge of the North China Plain.

Four small whole arches were incorporated within the structure of the main bridge. They were an innovation of great consequence in bridge-building, for they were the world's first arched spandrels. Li Chun found that by punching these holes in the ends of the bridge he could accomplish several things at once: flood waters could rush through them, lessening the

The Great Stone Bridge spanning the Jiao river in northern China. Constructed in 610 AD, it was renovated in the 20th century and is still in use.



chance that the main bridge would be swept away at its supports in a sudden flood; the total weight of the bridge could be lessened, thereby diminishing the tendency to buckle by the ends sinking down into the river banks; and vast quantities of material could be saved, which would normally have gone to make solid ends for the bridge.

The Great Stone Bridge has a span of 37.5 metres. The largest surviving Roman whole arch bridge, the Pont Saint Martin near Aosta, spans 35.5 metres. But the average whole arch Roman bridge spanned between 18 and 25 metres, whereas whole arches in Roman aqueducts had an average span of about 6 metres.

The greatest segmental arch bridge in China is the famous "Marco Polo Bridge", often so named because Polo described it at length. Just west of Beijing, it crosses the Yongding river at the small town of Lugougiao, and is 213 metres in length, consisting of a series of eleven segmental arches extending one after another across the river, each with an average span of 19 metres. It was built in 1189 and is still heavily used by modern truck and bus traffic. Marco Polo thought this bridge "the finest in the world". ■

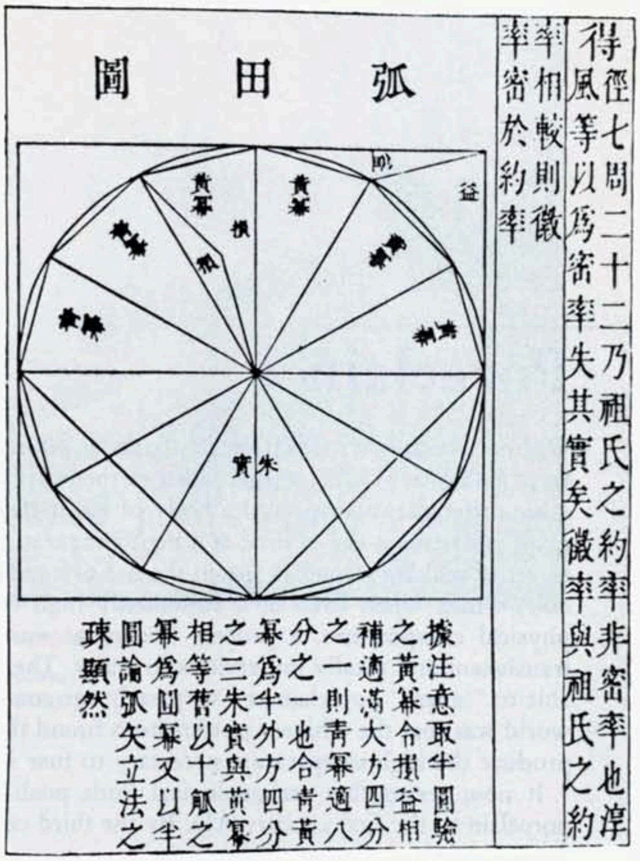
A refined value of *pi*

The irrational number *pi* can be computed to an infinite number of decimal places. It expresses the ratio of the circumference of a circle to its diameter, a relationship which cannot be framed in terms of whole numbers. (*Pi* is needed to compute the area of a circle or volume of a sphere.) The value of *pi* was computed by Archimedes to three decimal places, and by Ptolemy to four decimal places. But after that, for 1,450 years, no greater accuracy was achieved in the Western world. The Chinese, however, made great strides forward in computing *pi*.

One way in which the ancient mathematicians tried to approach an accurate value for *pi* was to inscribe polygons with more and more sides to them inside circles, so that the areas of the polygons (which could be computed) would more and more closely approach the area of the circle. Thus, they could try to find a value for *pi*, since the circle's area was found by using the formula containing it. (They could measure the diameter, and squeeze a polygon whose area they knew into the circle; the only unknown number would be *pi*, which could then be calculated.) Archimedes used a 96-sided polygon, and decided that *pi* had a value between 3.142 and 3.140.

The Chinese tried to sneak up on *pi* in the same fashion. Liu Hui in the third century AD started by inscribing a polygon of 192 sides in a circle, and then went on to inscribe one of 3,072 sides which "squeezed" even closer. He was thus able to calculate a value of *pi* of 3.14159. At this point, the Chinese overtook the Greeks.

But the real leap forward came in the fifth century AD, when truly advanced values for *pi* appeared in China. The mathematicians Zu Chongzhi and Zu Gengzhi (father and son), by means of calculations which have been lost, obtained an "accurate" value of *pi* to ten decimal places, as 3.1415929203. The circle used for the inscribing of the polygons is known to have been 10 feet across. This value for *pi* was recorded in historical records of the period, but the actual books of those mathematicians have vanished over the centuries. Nine hundred years later, the mathematician Zao Yugin (about 1300 AD) set himself to verify this value of *pi*. He inscribed polygons in a circle with the enormous number of 16,384 sides. He thus confirmed the value given by the Zu family. ■



得徑七周二十二乃祖氏之約率非密率也淳風等以爲密率失其實矣徽率與祖氏之約率相較則徽率密於約率

弧田圖

據注意取半圓驗之黃冪令損益相補適滿大方四分之一則青冪適八分之一也合青黃冪爲半外方四分之三朱實與黃冪相等舊以十觚之冪爲圓冪又以半圓論弧矢立法之疎顯然

Diagram showing a method used by the Chinese mathematician Liu Hui in 264 AD to calculate the value of *pi*.

The decimal system

The decimal system, now fundamental to modern science, originated in China. Its use can be traced back to the fourteenth century BC, the archaic period known as the Shang Dynasty, though it evidently was used long before that.

An example of how the ancient Chinese used the decimal system may be seen from an inscription dating from the thirteenth century BC, in which "547 days" is written "Five hundreds plus four decades plus seven of days".

In computation, the Chinese used counting rods on counting boards. To "write" ten involved placing a single rod in the second box from the right, and leaving the first empty, to signify zero. To change the ten to eleven, a single rod was added in the first box. To "write" 111, single rods were placed in the first, second and third boxes. Apparently from the earliest times, the decimal place system for numbers was literally a *place* system; the Chinese *placed* counting rods into actual boxes.

The fact that the decimal system existed from the very beginnings of mathematics in China gave the Chinese a substantial advantage, laying a foundation for most of the advances they later made. ■


This basin of *yue* ware, with a pale green glaze, is one of the oldest surviving pieces of porcelain (3rd century AD).

Porcelain

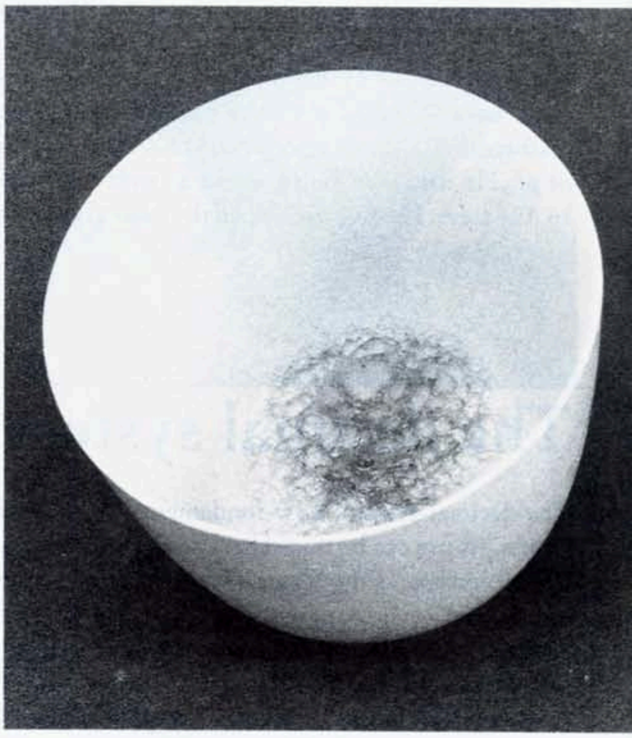
Ordinary pottery is made from clay baked in a kiln at temperatures ranging from 500°C to 1150°C, and is called earthenware. Porcelain is something quite different: it consists of a body of fused clay covered by a glaze, a glassy substance, and is fired at a high temperature—about 1280°C. The secret of making porcelain lies in the use of a pure clay, kaolin or China clay, which when fired at a sufficiently high temperature changes its physical composition, a process known as vitrification, and becomes translucent and totally impervious to water. The reason why China was able to "invent" porcelain at a very early age compared to the rest of the world was that the Chinese potters both found the clay and were able to produce the high temperature necessary to fuse it.

It now seems that archaeological finds push back the date of true porcelain to the first century AD. By the third century AD, in any case, true porcelain was undeniably in use.

By the Song Dynasty (960-1279), porcelain had reached a very high degree of artistry. Porcelain manufacture by this time was a highly organized trade employing hundreds of thousands of people. There were teams of men who specialized in washing the clay, others who concerned themselves only with glazes, others who maintained the kilns, and so on. One kiln of this period which has been excavated could accommodate 25,000 pieces of porcelain at a single firing. It was built on the slope of a hill, the gentle incline of about 15° reducing the speed of the flames through the kiln. The sophistication of the kilns was most impressive. Some were fired by burning wood, while others were down-draught burners of charcoal. Control of the firing process was of the utmost precision. In the Ming Dynasty (1369-1644), when the famous blue and white ware was largely produced, the best lustrous quality of the cobalt blue pigment could only be obtained at certain specific temperatures, and in a reducing (de-oxidizing) flame.

The secrets of porcelain manufacture were jealously guarded, and visitors from Europe such as Marco Polo could but gape and wonder. Porcelain objects were still a very great rarity in Europe by the fifteenth century. They were gifts for kings and potentates. Not until 1520 did the first sample of kaolin clay reach Europe, brought by the Portuguese. Europeans then thought that if only they could find deposits of this white clay, they would be able to make porcelain. But kaolin clay alone is far from sufficient for the making of porcelain.

The countless experiments carried on with various earths and solid substances in furnaces eventually had a most unpredictable result. Scientists and craftsmen began to notice that upon cooling down again, molten minerals could crystallize. Until this began to be observed, Western scientists had been convinced that crystals could only be formed from liquids. About the middle of the eighteenth century in Europe, the idea began to gain ground that perhaps the Earth's rocks could have been formed from the cooling of molten masses of lava. In 1785 the geologist James Hutton presented his revolutionary new theory of the Earth based on this idea. And so, one of the great scientific advances in the Western world took place as a direct consequence of the attempts by Europeans to find the secret of porcelain manufacture. ■


White porcelain goblet with thick, finely-crackled glaze. Tang Dynasty (618-907 AD).

Traditional kilns for firing porcelain (late-18th-century painting).

A late-18th-century painting of a Chinese street vendor selling joss-sticks and matches.

Matches

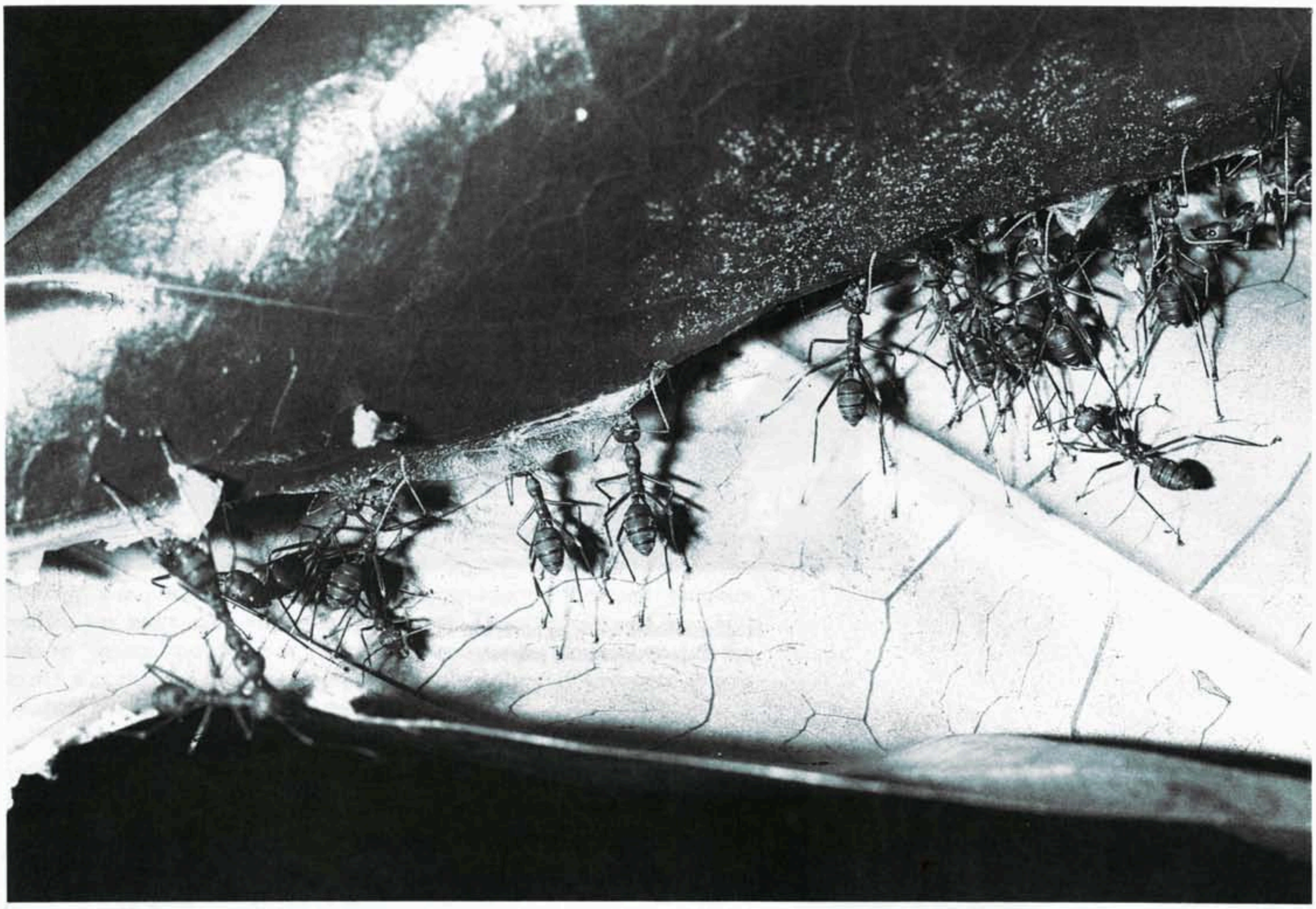
The first version of a match was invented in the year 577 AD by impoverished court ladies during a military siege, in the short-lived Chinese kingdom of the Northern Qi. Hard-pressed during the siege, they must have been so short of tinder that they could otherwise not start fires for cooking or heating.

Early matches were made with sulphur. A description is found in a book entitled *Records of the Unworldly and the Strange* written about 950 by Tao Gu:

"If there occurs an emergency at night it may take some time to make a light to light a lamp. But an ingenious man devised the system of impregnating little sticks of pinewood with sulphur and storing them ready for use. At the slightest touch of fire they burst into flame. One gets a little flame like an ear of corn. This marvellous thing was formerly called a 'light-bringing slave', but afterwards when it became an article of commerce its name was changed to 'fire inch-stick'."

There is no evidence of matches in Europe before 1530. Matches could easily have been brought to Europe by one of the Europeans travelling to China at the time of Marco Polo, since we know for certain that they were being sold in the street markets of Hangzhou in the year 1270 or thereabouts. ■

Biological pest control



Carnivorous ants, used in China for many centuries to protect mandarin orange trees from predators.

For 1,700 years, the Chinese have controlled insect pests by biological means, using one insect to kill another. Perhaps their most striking and important use of biological pest control was in the use of yellow citrus killer-ants to protect mandarin trees. Here is how a text of 304 AD, *Records of the Plants and Trees of the Southern Regions,* describes the use of the carnivorous yellow ants:

"The mandarin orange is a kind of orange with an exceptionally sweet and delicious taste.... The people of Jiaoshi [Tonkin] sell in their markets [carnivorous] ants in bags of rush matting. The nests are like silk. The bags are all attached to twigs and leaves which, with the ants inside the nests, are for sale. The ants are reddish-yellow in colour, bigger than ordinary ants. These ants do not eat the oranges, but attack and kill the insects which do. In the south, if the mandarin orange trees do not have this kind of ant, the fruits will be damaged by many harmful insects, and not a single fruit will be perfect."

This biological pest control first came to Western attention when a paper on the subject was published in the *North China Herald* on 4 April 1882. But it was not until a serious outbreak of citrus canker occurred in the Florida citrus groves in the 1910s that a plant physiologist was sent to China by the US Department of Agriculture in 1915 to search for canker-resistant oranges, and discovered the citrus ants. In 1958, a Chinese scientist, Chen Shou-jian, recommended a renewed study of the ants. Their use in Chinese orange groves continues to this day. ■

Petroleum and natural gas

It is probably a conservative estimate to say that the Chinese were burning natural gas for fuel and light by the fourth century BC. The deep boreholes drilled for brine also yielded natural gas from time to time. These methane gas deposits tended to occur under the brine, but many boreholes, including those intended for brine, yielded *only* natural gas and were known to the Chinese as "fire wells". These boreholes were being drilled systematically for brine by at least the first century BC, so that deep supplies of natural gas were tapped from that date by boreholes going down over 100 metres. And the systematic search for natural gas itself by deep drilling is recorded in the second century AD.

Chang Qu in 347 recorded in his book *Records of the Country South of Mount Hua:*

"At the place where the river from Bupu joins the Huojing River, there are fire wells; at night the glow is reflected all over the sky. The inhabitants wanted to have fire, and used to ignite the gas outlets with brands from household hearths; after a short time there would be a noise like the rumbling of thunder and the flames would shoot out so brilliantly as to light up the country for several dozen *li* around. Moreover they use bamboo tubes to 'contain the light', conserving it so that it can be made to travel from one place to another, as much as a day's journey away from the well without its being extinguished. When it has burnt no ash is left, and it blazes brilliantly."

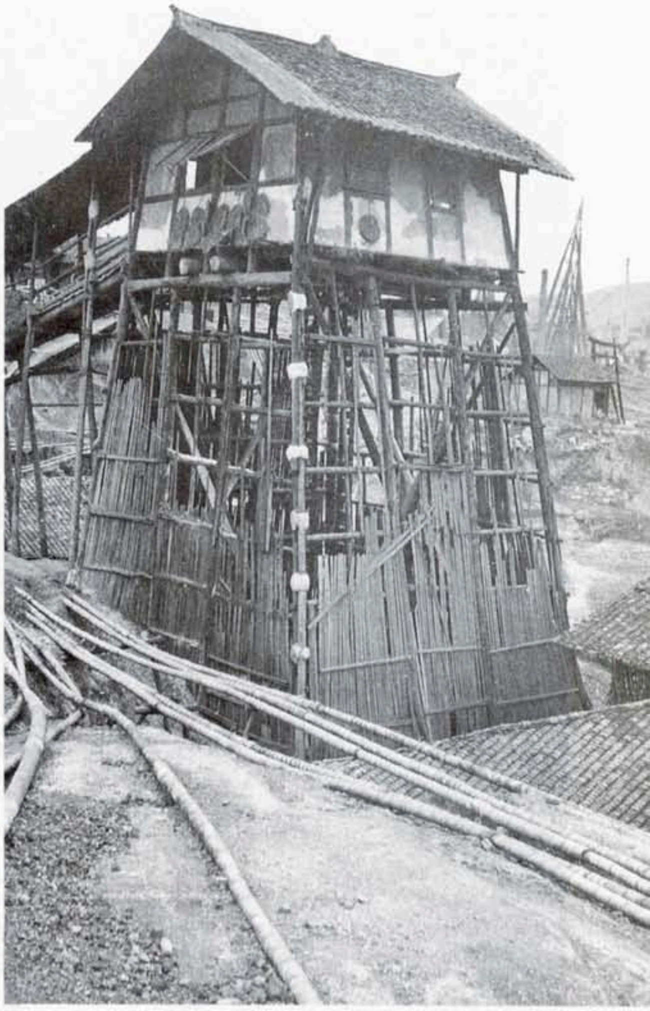
Bamboo pipelines did indeed carry both brine and natural gas for many kilometres, sometimes passing under roads and sometimes going overhead on trestles.

The ignition and use of the natural gas for light and fuel posed problems which were successfully overcome by the ancient Chinese. Old texts describe in some detail the complicated arrangements which were eventually adopted to control the burning of natural gas. The gas from the "fire wells" was fed first into a large wooden chamber about 3 metres below ground level over the mouth of the borehole. It was basically a cone-shaped barrel into which an underground pipe also conveyed air. The chamber therefore acted as a great carburettor, feeding into banks of pipes which led to other smaller conical chambers which rested on the surface of the earth. These too took in air, with a variety of entry pipes which could be opened or closed, so that a fine-tuning of the "engine" was possible by a continuous manipulation of the fuel/air mixture. If the pressure of the mixture were to flag, dangerous flash-backs and explosions could occur, so the main chamber would be opened up further. But fires could result if the mixture were too rich, so surplus gas was allowed to escape through what was called a "sky thrusting pipe" exhaust system.

Flames less than 50 cm high were used for other purposes, such as providing lights in certain Sichuan towns. The gas was also available for heating in these towns, though details of how it was employed are lacking. It seems doubtful that proper gas stoves existed, and it is more likely that the heating applications were generally for cooking and boiling uses.

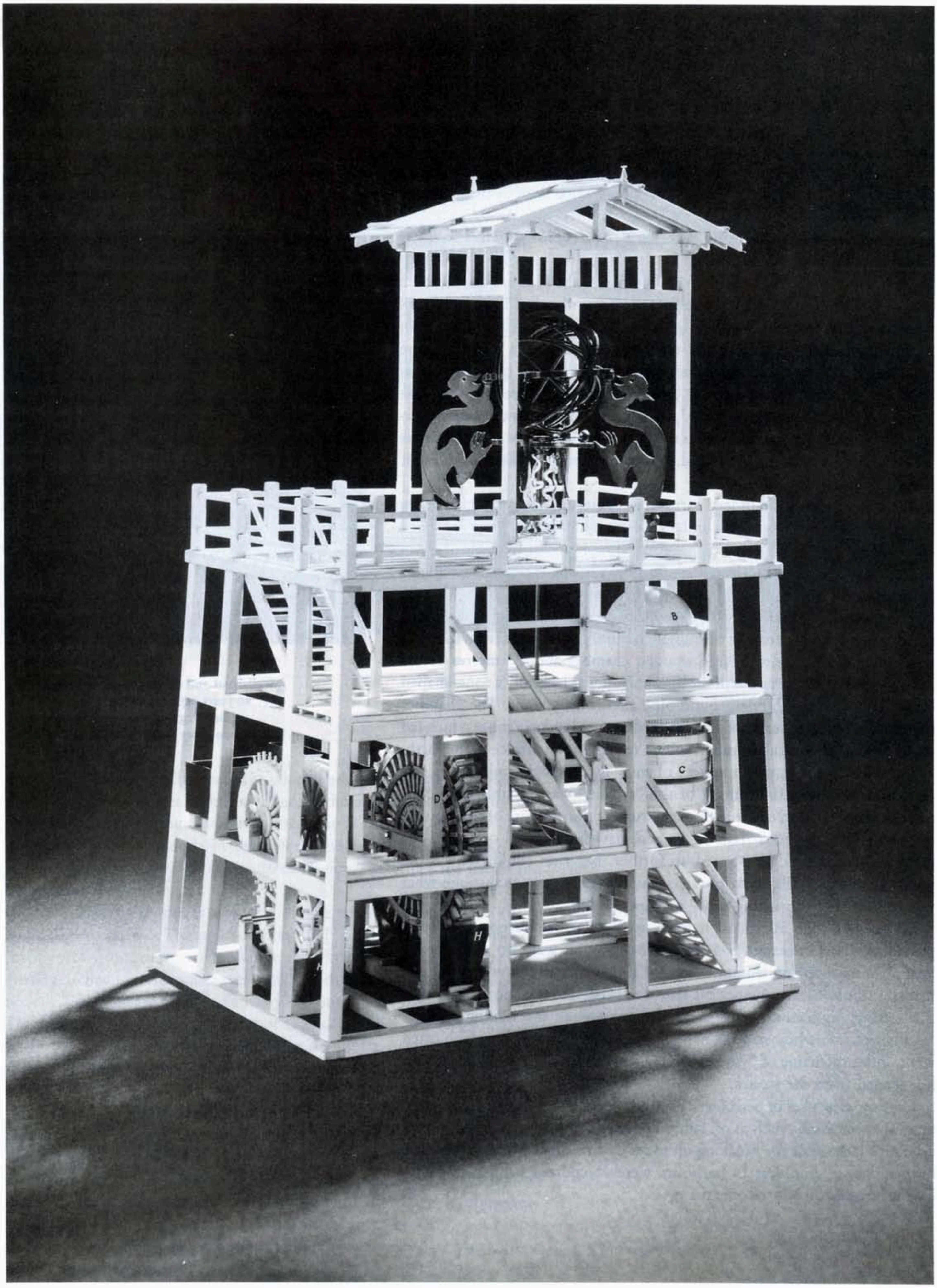
Other portable heat sources included petroleum products, which often went under the name of "stone lacquer" because they looked like lacquer but seeped from the stones.

The domestic uses of petroleum products seem to have been confined to modest applications such as oil lamps and oil-fired torches, but they were used on a large scale for breaking up rocks by fire. Since burning oil could burn in water, boulders in harbours were sometimes broken apart by having burning oil poured over them. ■



Well-head and derricks photographed over 40 years ago in Sichuan Province. In foreground, the traditional bamboo pipes which led the natural gas to nearby towns.

The mechanical clock



The Chinese did not invent the first clock of any kind, merely the first mechanical one. Water clocks had existed since Babylonian times, and the earliest Chinese got them indirectly from that earlier civilization of the Middle East.

The world's first mechanical clock was built by the Chinese Tantric Buddhist monk and mathematician Yixing (683-727). This was actually an astronomical instrument which served as a clock, rather than simply a clock. A contemporary text describes it:

"[It] was made in the image of the round heavens and on it were shown the lunar mansions in their order, the equator and the degrees of the heavenly circumference. Water, flowing into scoops, turned a wheel automatically, rotating it one complete revolution in one day and night [24 hours]. Besides this, there were two rings fitted around the celestial sphere outside, having the sun and moon threaded on them, and these were made to move in circling orbit. ... And they made a wooden casing the surface of which represented the horizon, since the instrument was half sunk in it. It permitted the exact determinations of the time of dawns and dusks, full and new moons, tarrying and hurrying. Moreover, there were two wooden jacks standing on the horizon surface, having one a bell and the other a drum in front of it, the bell being struck automatically to indicate the hours, and the drum being beaten automatically to indicate the quarters. All these motions were brought about by machinery within the casing, each depending on wheels and shafts, hooks, pins and interlocking rods, stopping devices and locks checking mutually [i.e. the escapement]".

Yixing's clock was, like water clocks, subject to the vicissitudes of the weather. In order to keep the water in them from freezing, torches generally burnt beside them. Therefore, in the next great clock of which we have accounts in China, mercury was substituted for water because of the freezing problem. This clock was built by Zhang Sixun in 976 AD. Zhang Sixun's clock was apparently much larger than Yixing's. It was certainly far more complex. The dynastic history of the time describes it:

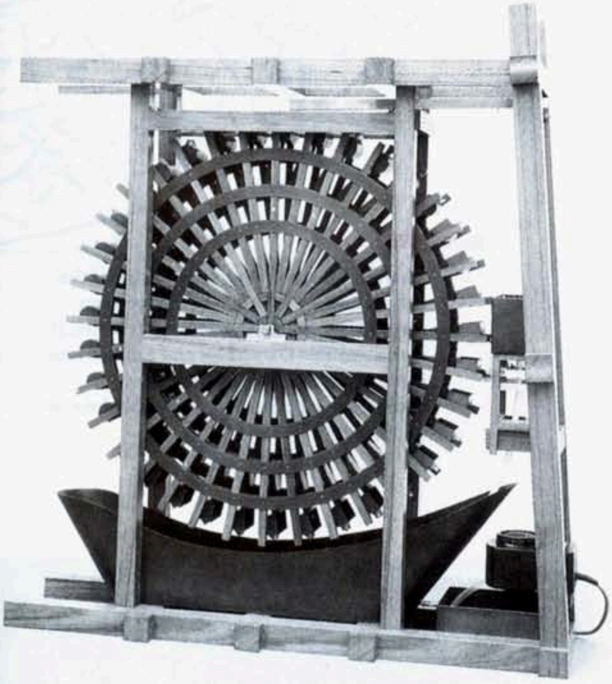
"... a tower of three storeys each over 3 metres in height, within which was concealed all the machinery. It was round at the top to symbolize the heavens and square at the bottom to symbolize the earth. Below there was set up the lower wheel, lower shaft, and the framework base. There were also horizontal wheels, vertical wheels fixed sideways, and slanting wheels; bearings for fixing them in place; a central stopping device and a smaller stopping device [i.e. the escapement] with a main transmission shaft. Seven jacks rang bells on the left, struck a large bell on the right, and beat a drum in the middle to indicate clearly the passing of the quarter-hours. Each day and night [i.e. each 24 hours] the machinery made one complete revolution, and the seven luminaries moved their positions around the ecliptic. Twelve other wooden jacks were also made to come out at each of the double-hours, one after the other, bearing tablets indicating the time..."

All of these efforts were preparatory for the greatest of all Chinese medieval clocks, the "Cosmic Engine" of Su Song, built in the year 1092.

Su Song's clock was actually an astronomical clock tower more than 10 metres high, like the previous one of Zhang. But on top of Su Song's tower was additionally a huge bronze power-driven astronomical instrument called an armillary sphere, with which one could observe the positions of the stars. A celestial globe inside the tower turned in synchronization with this sphere above, so that the two could constantly be compared. We are told that the observations made on the demonstrational globe inside and by the observational sphere above "agreed like the two halves of a tally".

On the front of the tower was a pagoda structure of five storeys, each having a door through which mannikins and jacks appeared ringing bells and gongs and holding tablets to indicate the hours and other special times of the day and night. All of these time-indicators were operated by the same giant clock machinery which simultaneously turned the sphere and the globe.

Knowledge of the principles of Su Song's clock spreading to Europe led to the development of mechanical clocks in the West two centuries later. ■



Model of Su Song's great astronomical clock of 1092. The framework has been left uncovered to reveal the mechanism. The original clock tower was 10 m high, with a power-driven armillary sphere at the top for observing the stars. Inside the tower, a celestial globe (B) turned in synchronization with the sphere. The central element was the escapement (D, and detail below), which was turned clockwise by water or mercury pouring from the tank on the right.

Paper money

The Chinese invented paper money at the end of the eighth or beginning of the ninth century AD. Its original name was "flying money" because it was so light and could blow out of one's hand. The first paper money was, strictly speaking, a draft rather than real money. A merchant could deposit his cash in the capital, receiving a paper certificate which he could then exchange for cash in the provinces. This private merchant enterprise was quickly taken over by the government in 812. The technique was then used for the forwarding of local taxes and revenues to the capital. Paper "exchange certificates" were also in use. These were issued by government officials in the capital and were redeemable elsewhere in commodities such as salt and tea.

Real paper money, used as a medium of exchange and backed by deposited cash, apparently came into being early in the tenth century, in the southern province of Sichuan, as a private enterprise. Early in the eleventh century the government authorized sixteen private businesses or "banks" to issue notes of exchange; but in 1023 the government usurped this private enterprise and set up its own official agency to issue bank notes of various denominations which were backed by cash deposits. The money issued by this bank had printed on it a notice to the effect that it was good for only three years, and gave the dates. By 1107, notes were being printed with multiple blocks in no less than six colours.

The issuing of paper money by the government took on enormous proportions. By 1126, seventy million strings (each string being equal to one thousand pieces of "cash") had been officially issued. Vast amounts of this paper money were not backed by any deposits, and a horrifying inflation occurred.

Another problem which soon arose was counterfeiting. Since anyone can print on pieces of paper, the authority must make the processes of manufacture of its paper money so intricate that they cannot be exactly reproduced. Complex manufacturing secrets were thus adopted quite early, and included multiple colourings, immensely complex designs, and a mixture of fibres in the paper. The basic material for the paper of paper money was the bark of mulberry trees, and silk was sometimes incorporated. One could hand in soiled or worn-out notes for new ones, but had to pay the small cost of the printing of the replacement.

When the Mongols came to power in China, they issued a quaint form of paper money called "silk notes". The deposits behind this currency were not precious metals but bundles of silk yarn. By 1294, Chinese silk notes were being used as money as far afield as Persia. In 1965, two specimens of "silk notes" were found by archaeologists.

Paper money under the later Ming Dynasty was not so effective. The Ming issued in 1375 a new note called the "Precious Note of Great Ming". It was issued in one denomination only throughout the 200 years in which it was the legal tender. This was naturally very inconvenient for all commercial purposes, although copper coins were permitted to circulate, and these must have provided the small change necessary in everyday life. Through inflation, the Precious Note gradually lost its value and was replaced by silver. ■

This diagram showing knowledge of the magnetic declination is taken from an early 10th-century geomantic treatise. It is entitled *The Directions and Emanations of the Floating Needle,* that is, the compass needle floating in a pool of water or mercury.

Declination of the Earth's magnetic field

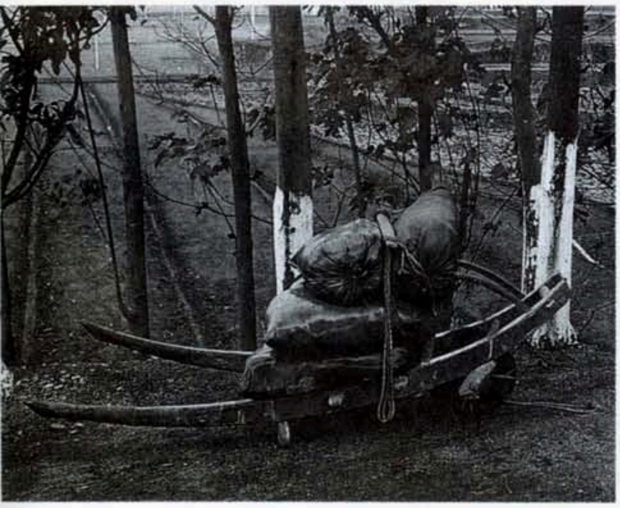
The Earth's magnetic field is oriented slightly askew from what might be expected. The magnetic North Pole is about 1,900 km from the geographical true north of the planet. The difference between a finger pointing at the true geographical North Pole and a compass needle pointing at the magnetic North Pole is known as the angle of declination or variation; it is not constant, and continually shifts. By the eighth or ninth century AD at the latest, the Chinese had discovered this magnetic declination.

As Needham says, in doing so the Chinese were "antedating European knowledge of the declination by some six centuries. The Chinese were theorizing about the declination before Europe even knew of the polarity...." The magnetic compass and the polarity of the Earth's field are not mentioned in any Western writing until 1190 AD, and the Chinese had had the compass for a good fifteen hundred years before that. In his *Dream Pool Essays* of 1086, the medieval Chinese scientist Shen Gua wrote on magnetic declination that "Magicians rub the point of a needle with a lodestone; then it is able to point to the south. But it always inclines slightly to the east, and does not point directly at the south." ■

The wheelbarrow

The wheelbarrow was apparently invented in south-western China in the first century BC by a semi-legendary personage called Guo Yu.

The oldest surviving picture of a wheelbarrow dates from about 100 AD. It is a frieze relief from a tomb-shrine excavated near Xuzhou (Jiangsu) which very clearly shows a wheelbarrow with a man sitting on it. There are several other illustrations from this period, the Han Dynasty, indicating that wheelbarrows were increasingly commonplace.



The earliest descriptions of the construction of wheelbarrows are couched in coy and obscure language. For the first few centuries, wheelbarrows were of great military importance, and specifics of their construction were closely guarded secrets. Some carried men on seats, and others carried supplies. They were also used to form protective movable barriers against cavalry charges. The ingenuity of the Chinese at exploiting the wheelbarrow was limitless, and they were even given sails, with which they could achieve speeds over land or ice of 60 kilometres per hour.

A large variety of designs existed, some with wheels in the dead centre, with the weight resting entirely on the axle, and others with wheels forward. Some had tiny wheels, some had huge ones. Additional small wheels were sometimes fitted in front to ease the passage over potholes and other obstacles. Practically all shapes and sizes of wheelbarrow existed—and still exist—in China. ■

Lacquer

Carved lacquer box in the shape of a plum blossom decorated with clouds and dragons. It was produced during the reign of the Ming Dynasty Emperor Longqing (1567-1572).

Lacquer was in use by at least the thirteenth century BC in China. Queen Fu Hao of that date was buried in a lacquered coffin, discovered when her intact tomb was excavated in 1976 at Anyang. Needham has written that: "Lacquer may be said to have been the most ancient industrial plastic known to man."

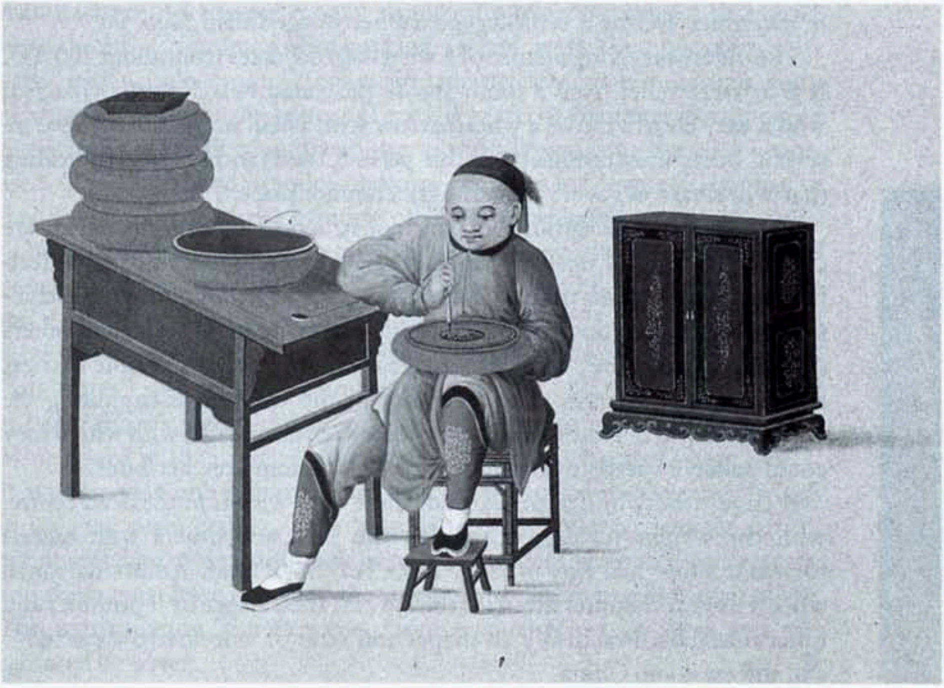
Lacquer is obtained rather like rubber, by tapping the sap of tree trunks. The lacquer tree (*Rhus vernicifera,* recently named *verniciflua* by botanists) is indigenous to China but not to Europe. It is particularly common in central China, growing at altitudes between 900 metres and 2,000 metres. The trees are tapped in summer and left to recover after a period of five to seven years, though in some cases they are cut down after tapping, and an inferior lacquer is obtained from their branches. The largest amount of lacquer a tree can produce is about 50 grams.

Lacquer is a plastic varnish which has remarkable powers of preservation, strength and durability. Strong acids and alkalis cannot damage it; it cannot be affected by heat less than 200°-250°C; it cannot be damaged by water or other liquids; it is insoluble to most solvents; and it is resistant to bacterial attack.

Lacquer was used for kitchen utensils thousands of years ago in China. Wood, bamboo or cloth utensils coated with many layers of thin lacquer formed the standard dinner service for rich Chinese in place of bronze vessels. They were able to withstand the heat of cooking and serving of food as well as metal. Chinese emperors gave lacquered articles to their officials as recognition for their services, and the monetary value of lacquerware actually exceeded that of bronzes.

Lacquer was used in China for furniture, screens, pillows and boxes of all sorts. It was worn as bonnets and shoes. Weapon accessories, such as sword scabbards, bows and shields were made of it. Lacquers were often inlaid with gold and silver or tortoiseshell. The fluidity of the lacquered surface when applied made possible a form of Chinese decoration which was as free and spontaneous as could be imagined, and this had a major impact on ancient Chinese art.

The lacquer industry in ancient China was highly organized, in the traditional Chinese bureaucratic way. There were both private and state lacquer manufacturing centres. There is a lacquered wood wine cup which can be dated precisely to the year 4 AD by an extraordinary inscription which, besides giving the date of manufacture, lists seven artisans involved in making the cup and five other officials of the company. Twelve people to produce a single cup, nearly half of them functionaries who perhaps never



A craftsman cuts decorative incisions in a lacquer bowl (late-18th-century painting).

even saw it! But on the other hand, it indicates also the use of something very like the modern industrial production-line.

As early as the second century BC, the Chinese had made important chemical discoveries about lacquer. They found a way to keep it from going hard by evaporation—they threw crabs into lacquer to keep it liquid!

Crustacean tissue does in fact contain powerful chemicals which inhibit certain enzymes, including the one which makes lacquer solidify! Needham comments on this bizarre affair as follows:

"There can be no doubt that the ancient Chinese, before the second century BC, had accidentally discovered a powerful laccase inhibitor. ... So great an interference with the course of nature, analagous to the arrest of a spontaneously occurring rigidification and ageing process, must have seemed highly significant to the alchemists, preoccupied as they were by the preservation of supple youth and the postponement or elimination of ankylosis and death."

Not only did the perpetual liquefaction of lacquer pose a model for immortality, in this proto-industrial biochemistry, but lacquer accompanied a Chinese from cradle to grave—he would be fed as a baby from lacquer vessels with lacquer ladles, and in death he would be buried in a beautifully ornamented lacquer coffin. ■

Red lacquer throne of the Qing Dynasty, dating from the period 1736-1796.

The first contour transport canal

The world's first contour transport canal, the Magic Canal (Lingqu), was constructed in China in the third century BC. This was indeed a most impressive pioneering achievement. It was constructed by the engineer Shi Lu on the orders of the Emperor Qin Shih Huangdi. The impetus for this innovative type of canal was to assist in supplying the emperor's armies sent south in 219 BC to conquer the people of Yue. We are told by the great historian Sima Qian that:

"[the emperor] sent the Commanders (Zhao) Tuo and Tu Zhu to lead forces of fighting-men on boats with deck-castles to the south to conquer the countries of the hundred tribes of Yue. He also ordered the Superintendent (Shi) Lu to cut a canal so that supplies of grain could be sent forward far into the region of Yue."

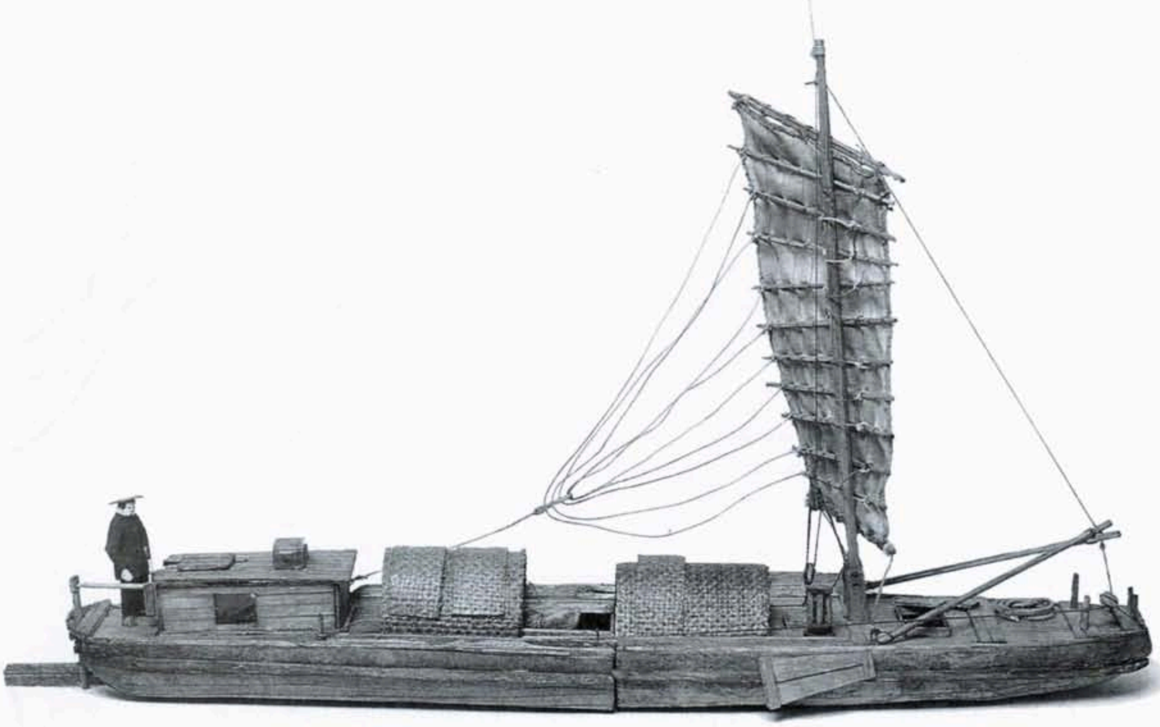
The Magic Canal is just over 32 kilometres long. Its chief interest is thus not its length, which is unexceptional. The construction of the Magic Canal, linking as it did two rivers flowing in opposite directions, made possible the continuous inland navigation of barge transport for a distance of 2,000 kilometres in a direct line, from the 40th to the 22nd parallel. One could thus sail inland from the latitude of Beijing in the north as far as Canton and the sea—to what is today Hong Kong. The Magic Canal was the final link in the chain.

The problem that had to be overcome was that the River Xiang with its source at Mount Haiyang, flowed northwards, while the nearby River Li flowed southwards. If only one could get a boat from one to the other!—for the Xiang led eventually to the Chang Jiang and the Li joined a tributary of the West River and led to Canton. Near the little village of Xing'an, the Xiang and the Li, in a landscape of limestone hills, are only 5 kilometres apart. Simply joining them was not sufficient. Another solution had to be found.

There was a saddle in the hills at this point along which a canal could be dug. The rivers themselves were unruly and a lateral transport canal had to be dug alongside the Xiang river for 2.4 kilometres at a more even gradient than the river itself had. At the other end, some 22 kilometres of the Li river had to be canalized in order to regulate it and make navigation possible. Only with the two rivers "tamed" at either end like this could a 5-kilometre canal then be dug to join them. A mound shaped like a snout was constructed in the middle of the swiftly running Xiang to divide its flow, and lead off much of the rushing water. It was backed up by two spillways, and further spillways were made lower down. Several bridges at Xing'an were constructed to cross the canal, which was 1 metre deep and 4.5 metres wide. The system of division of the waters and spillways resulted in only about three-tenths of the water from the Xiang entering the connecting canal, so that it was not overwhelmed.

By being built along the contours of the saddle in the hills, the canal was nearly level. Eighteen flash-lock gates were there by the ninth century at the latest, reducing the number of towers needed for barges by the tenth or eleventh century. The Magic Canal came to be considered a sacred waterway, with a dragon as its governing spirit. A modern railway bridge goes right over the old Magic Canal, which is still used. ■

This type of articulated junk used for transporting freight was specially designed to negotiate the many sharp bends and shallows of the Grand Canal, an immense waterway some 1,800 km long which was completed in the 14th century. The prow and the stern of the long, narrow boat can be separated and sailed independently. The mast can be lowered to enable the junk to pass beneath low bridges. Below, the Grand Canal today, at Wuxi.



Immunology

The origins of inoculation against smallpox in China are mysterious. We know that the technique originated in the southern province of Sichuan, where there is a famous mountain called Emeishan which is known for its connections with both Buddhism and Taoism. The Taoist alchemists who lived as hermits in the caves of that mountain possessed the secret of smallpox inoculation in the tenth century AD.

The technique first came to public attention when the eldest son of the Prime Minister Wang Dan (957-1017) died of smallpox. Wang desperately wished to prevent this happening to other members of his family, so he summoned physicians, wise men and magicians from all over the Empire to find some remedy. One Taoist hermit came from Emeishan. This monk or nun brought the technique of inoculation and introduced it to the capital.

Inoculation has certain dangers which set it apart from the later technique of vaccination. When one is inoculated, one has the live virus inserted into one's body. When the process is successful, one is immune for life. But the process can simply be one of direct exposure to the disease, so that one ends up with smallpox. With vaccination, the immunity conferred is only temporary, so that vaccinations have to be given every few years as "boosters". This is because vaccination uses dead viruses or some other kind of denatured virus (perhaps a related one) which cannot actually give one the disease.

At first sight it looks as if inoculation against smallpox must have been madness. Were not people just being given smallpox every time? The answer is no. And here we find the subtlety of the Chinese inoculators to be truly astounding. They practised a variety of methods for the attenuation of the deadly virus, so that the chances of getting the disease were minimized. First of all, there was a strong prohibition against taking the smallpox material from people who actually had the disease. The Chinese conceived of inoculation as a "transplant" of poxy material imagined as being like beansprouts which were just germinating. "To inoculate" in Chinese was called *zhong dou* or *zhong miao,* meaning "to implant the germs", or "implant the sprouts".

The method used was to put the poxy material on a plug of cotton, which was then inserted into the nose. The pox was thus absorbed through the mucous membrane of the nose and by breathing. (The technique of scratching the skin and putting the pox on the scratch seems to have developed long afterwards, possibly in Central Asia as the technique spread westwards.)

Ideally, inoculators chose poxy material from persons who had been inoculated themselves and had developed a few scabs. They also knew the difference between the two types of smallpox, *Variola major* and *Variola minor,* and they chose material from the latter, which was a less virulent form. Indeed, the favourite source of material was from the scabs of someone who had been inoculated with material from somebody who had been inoculated with material from somebody who had been inoculated.... In other words, a several-generations attenuation of the virus through multiple inoculations.

But there were other artificial methods used to attenuate the virus even further, so that it would be safer still. Here is one account from a work on *Transplanting the Smallpox* by Zhang Yan in the year 1741:

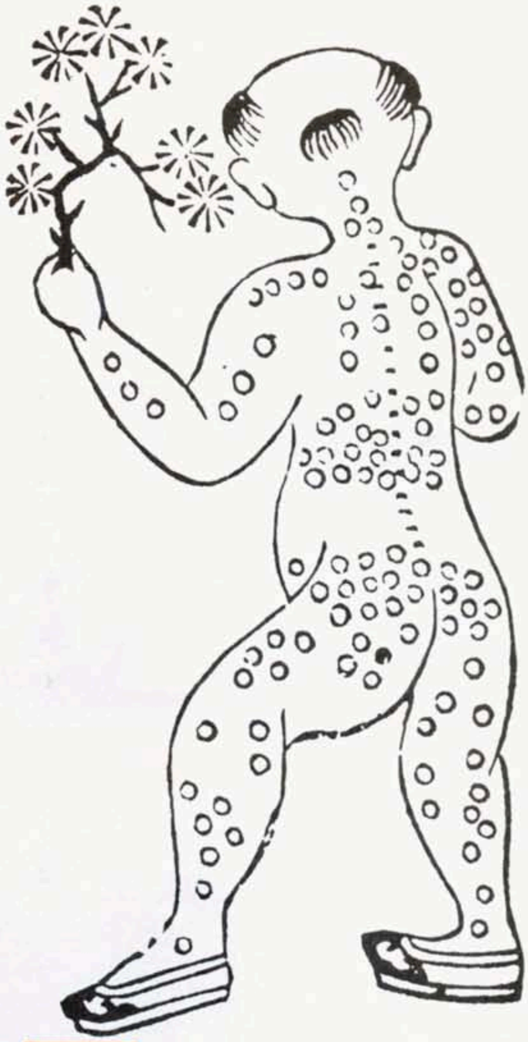
"Method of storing the material. Wrap the scabs carefully in paper and put them into a small container bottle. Cork it tightly so that the activity is not dissipated. The container must not be exposed to sunlight or warmed beside a fire. It is best to carry it for some time on the person so that the scabs dry naturally and slowly. The container should be marked clearly with the date on which the contents were taken from the patient.

"In winter the material has *yang* potency within it, so it remains active even after being kept from thirty to forty days. But in summer the *yang* potency will be lost in approximately twenty days. The best material is that which had not been left too long, for when the *yang* potency is abundant it will give a 'take' with nine persons out of ten; but as it gets older it gradually loses its activity, and finally it will not work at all. In situations where new scabs are rare and the requirement is great, it is possible to mix new scabs with the more aged ones, but in this case more of the powder should be blown into the nostril when the inoculation is done."

Needham comments on this and similar passages:

"Thus the general system was to keep the inoculum sample for a month or more at body temperature (37^{0}C) or rather less. This would certainly have had the effect of heat-inactivating some 80 per cent of the living virus particles, but since their dead protein would have been present, a strong stimulus to interferon production as well as antibody formation would have been given when inoculation was done."

In other words, 80 per cent of the smallpox viruses with which the Chinese were inoculated would have been dead ones which could not have given anyone smallpox. Instead, they would (as with vaccination) have stimulated the body to produce antibodies against smallpox. ■



The concept of vaccination appeared in China in the 10th century, when inoculation against smallpox was practised. Engraving of a child suffering from smallpox, above, is taken from the *Golden Mirror of Medicine* (1743).

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