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Science in East and West with special reference to China

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INTRODUCTION

In the autumn of 1979 I was invited by the Dean of the Faculty of Science, University of Hong Kong to give a series of four public lectures at his faculty while I was here as Honorary Professor at the Department of Chinese and an Honorary Research Fellow at the Centre of Asian Studies. I was expected to say something about the history of science and at the same time to bring in the development of traditional Chinese science and technology. I took the opportunity to demonstrate that many cultures had played a part leading to the development of modern science in Europe paying special attention to China, and how European science was brought to China until eventually Chinese scientists participated in the international enterprise of world science.

When I learned that the Centre of Asian Studies was considering publication of this series of lectures, I asked my colleague at Griffth University, Professor Colin Mackerras, Chairman of the School of Modern Asian Studies to read the manuscript. Whereupon Professor Mackerras approached the Centre of Asian Studies of this University proposing that this series of lectures be a joint publication of the two centres of learning. I am much indebted to both Professor Mackerras and Professor Cheng Te-k'un for reading through the manuscript and for their valuable suggestions. I also cherish the memory of the blue-print Professor Cheng Te-k'un made for the establishment of a Department of Chinese Studies in the University of Malaya, Kuala Lumpur in 1963 which I followed for nine years from 1964 to 1973. To Professor Cheng this book is dedicated.

It was through the generosity of two institutions of higher learning that this book was made possible. Griffith University granted me sabbatical leave to come to Hong Kong and the University of Hong Kong offered me visiting status for the duration of my stay here. To these two universities I wish to record a vote of thanks.

Ho Peng Yoke

CONTENTS

LECTURE I

SCIENCE IN THE ANCIENT WORLD I: EAST ASIA — DEVELOPMENT IN SPLENDID ISOLATION

The big pendulum in this series of four lectures swings from East to West and from West to East, but its motion is very complex, and definitely not simple harmonic. Its amplitude is not constant and nor is its period of motion. Borrowing the idea of harmonic analysis in physics, we may consider this big pendulum as the composite motion of many smaller pendulums, all moving with varying amplitudes and frequencies. The amplitudes of these pendulums seem to be dependant on economical, educational, geographical, intellectual, political, religious, and social factors. On analysis we shall find that many civilisations in different times of history have contributed, in their individual ways, to the growth of modern science, until it has eventually become a world enterprise participated by all mankind. In this first lecture we observe a smaller pendulum swinging in China from pre-history until it reaches a maximum point around the 13th century and then declines losing its amplitude. How it swings back again after the impact of science from Europe will be discussed in the last lecture. Even the general opinion on the origin of Chinese science is swinging like a pendulum. The current swing has been towards the west, but this trend is now constantly being affected by a new damping factor in the form of recent archaeological findings.

In the year 1548 a famous French physician by the name Jean Fernal (1497-1558) wrote:

> The world sailed round, the largest of the earth's continents discovered, the compass invented, the printing-press spreading knowledge, gunpowder revolutionising the art of war, ancient manuscripts rescued and the restoration of scholarship, all witness to the triumph of our New Age.[1]

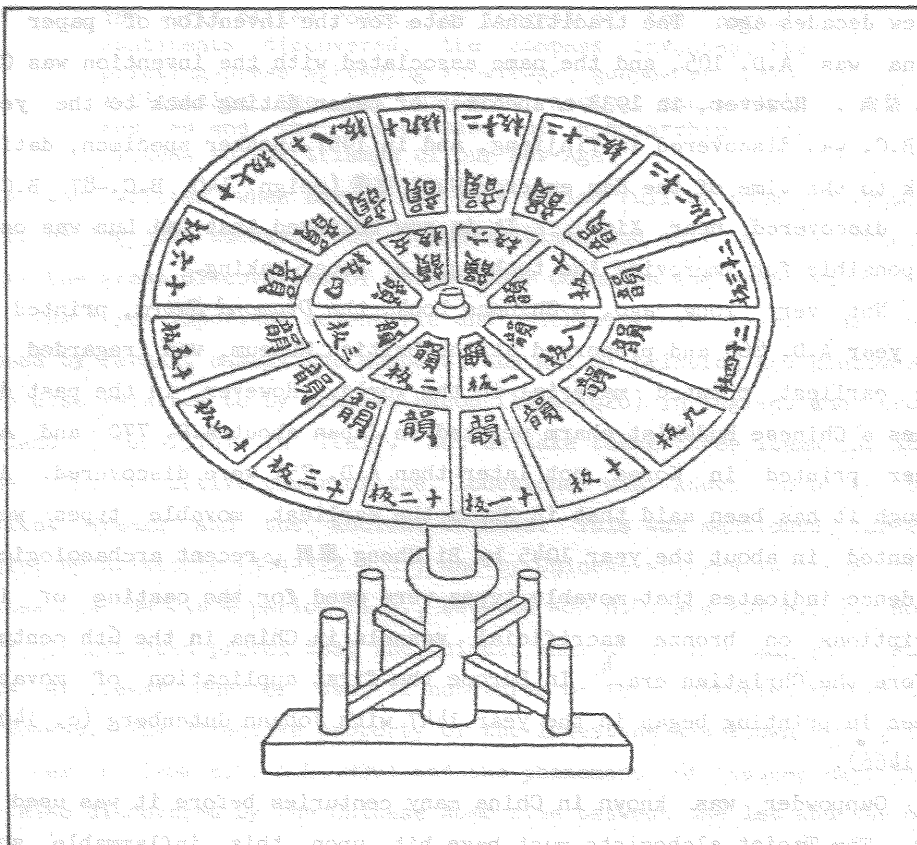
This was written when Europe was in a period full of hope and promise after having just emerged from mediaeval times and only a few decades after the great discoveries of Christopher Columbus and Magellan.

The three important scientific and technological inventions mentioned by Fernal, namely the compass, the art of printing and gunpowder, were also referred to by Francis Bacon (1561-1626) in England and Jerome Cardano (1501-1576) in Italy. Let us take these three items one at a time. The attractive power of the lodestone was known both to the ancient Greeks and the ancient Chinese. This was mentioned, for example, by Aristotle (384-322 B.C.) and by Chinese writers in the Warring States and the Qin 秦 period (i.e., between 480 B.C. and 207 B.C.). However, it has been proved that the Chinese knew about the magnetic compass at least one or two, if not three or four centuries before the Europeans. The directive property of the lodestone was known during the Han period (202 B.C.-A.D. 220) and the phenomenon of induced magnetism was also discovered by the Chinese some time between the 1st and the 6th century in the Christian era. By the 8th or 9th century the Chinese had further discovered the declination as well as the polarity of the magnet. In the 11th century the Chinese were already using the compass for navigation. This early form of the compass consisted of a magnet inserted into a piece of wood cut in the shape of a fish and set afloat on water.[2] In Europe the earliest record on the use of the magnet for navigation dated back only to 1190. At the time of Jean Fernal the Chinese knowledge of magnetism was still far ahead of Europe. It was only from the year 1600 that Europe has taken the lead in the study of magnetism with the work of William Gilbert (1540-1603).[3]

Paper-making and printing are generally acknowledged to have begun in China, and modern archaeological findings have even pushed the dates for their invention a few centuries earlier than what was thought until a few decades ago. The traditional date for the invention of paper in China was A.D. 105, and the name associated with the invention was Cai Lun 蔡倫. However, in 1933 a specimen of paper dating back to the year 49 B.C. was discovered in Yinjiang, and in 1957 another specimen, dating back to the time of the Han emperor Wudi 武帝 (reign 140 B.C.-87 B.C.) was discovered near Xian. It is now believed that Cai Lun was only responsible for improving the technique of paper-making.

Not very long ago, a Chinese book, the *Diamond Sutra*, printed in the year A.D. 868 and preserved at the British Museum, was regarded as the earliest printed material in the world. However, in the past decades a Chinese Buddhist charm printed in Japan about A.D. 770 and another printed in Korea not later than A.D. 751 were discovered. Although it has been said that in China the earliest movable types were invented in about the year 1045 by Bi Sheng 畢昇, recent archaeological evidence indicates that movable types were used for the casting of inscriptions on bronze sacrificial vessels in China in the 6th century before the Christian era.[4] In Europe the first application of movable types in printing began in the year 1447 with Johann Gutenberg (c. 1400-c. 1466).

Gunpowder was known in China many centuries before it was used in war. The Taoist alchemists must have hit upon this inflammable substance accidentally during their experiments when they mixed together saltpetre, sulphur and carbon. We find a written warning that this substance must be approached with extreme caution, because some alchemists had their laboratories set on fire, while others got their beards singed when this substance got out of their control. About the time of the emperor Yangdi (reign 604-618) of the Sui dynasty gunpowder was used in China simply for amusement in the form of fireworks displays and fire-crackers. The official history of the Song dynasty (960-1279),



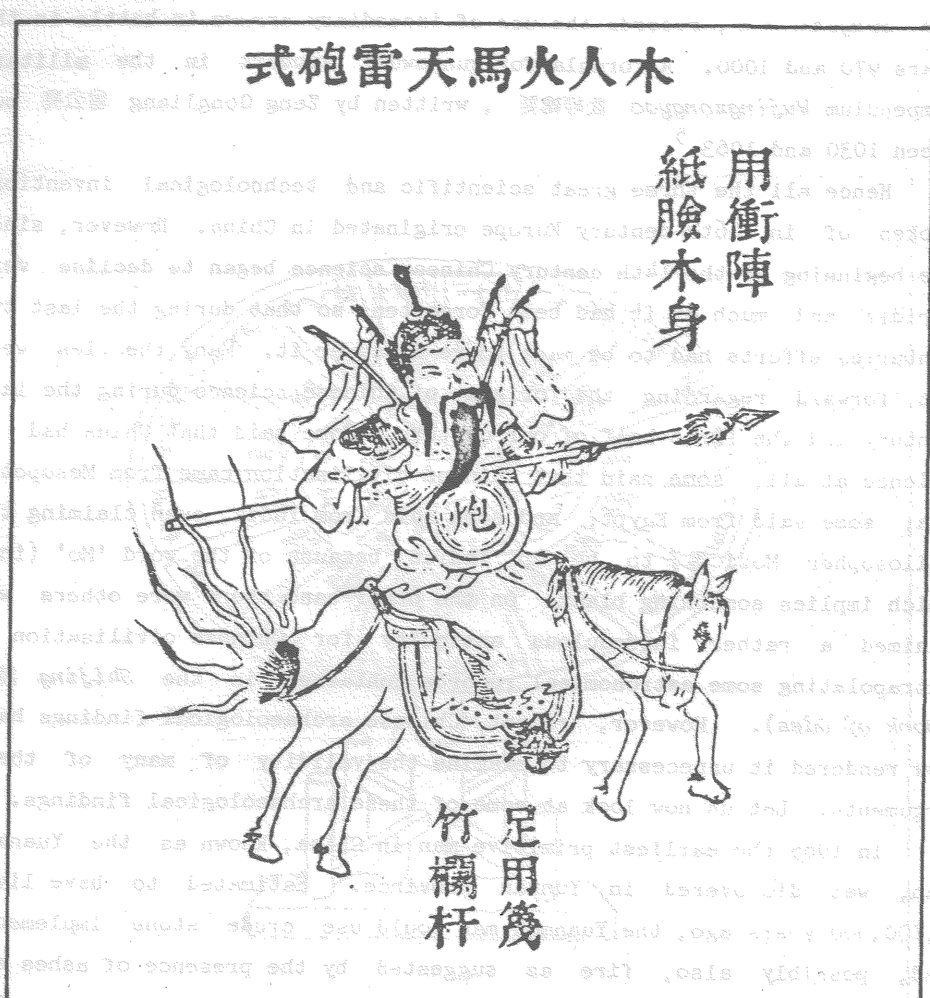
A movable-type printing machine invented by Wang Zhen c. A.D. 1290

the *Songshi* 宋史, records the use of incendiary arrows in battle in the years 970 and 1000. A formula for gunpowder appears in the military compendium *Wujingzongyao* 武經總要, written by Zeng Gongliang 曾公亮 between 1030 and 1063.[5]

Hence all the three great scientific and technological inventions spoken of in 16th-century Europe originated in China. However, since the beginning of the 14th century Chinese science began to decline very rapidly and much of it had been forgotten, so that during the last two centuries efforts had to be made to re-discover it. Many theories were put forward regarding the origin of Chinese science during the last century and the first half of our century. Some said that China had no science at all; some said that Chinese civilisation came from Mesopotamia; some said from Egypt; and some said from India, even claiming the philosopher Mozi 墨子 to be an Indian because of the word 'Mo' (ink) which implies something black. On the other hand there were others who claimed a rather incredulous antiquity for Chinese civilisation by extrapolating some astronomical records contained in the *Shijing* 詩經 (*Book of Odes*). However, recent Chinese archaeological findings have now rendered it unnecessary to examine the validity of many of these arguments. Let us now look at some of these archaeological findings.

In 1965 the earliest primitive man in China, known as the Yuanmou man, was discovered in Yunnan province. Estimated to have lived 1,700,000 years ago, the Yuanmou man could use crude stone implements and, possibly also, fire as suggested by the presence of ashes and charred bones. In 1975 and 1976 remains of other primitive men, estimated to have lived between 500,000 to 1,000,000 years ago, were found in Hubei province. Discovered earlier in 1963 and 1927 were the Lantian Man, who lived 0.6 million years ago in Shaanxi province and the Peking Man who lived about 0.5 million years ago in Zhoukoudian 周口店 respectively. Zhoukoudian was also inhabited about 19,000 years ago by the Upper Cave Man who definitely knew how to make fire.[6]

In 1952 the earliest known civilisation in the Neolithic Age in China was discovered at Banpo 半坡 in Shaanxi province. Dating back to



A bomb delivered to the enemy camp by a wooden figure in the guise of a mounted warrior from the Fire-Dragon Manual, a rare Ming military compendium.

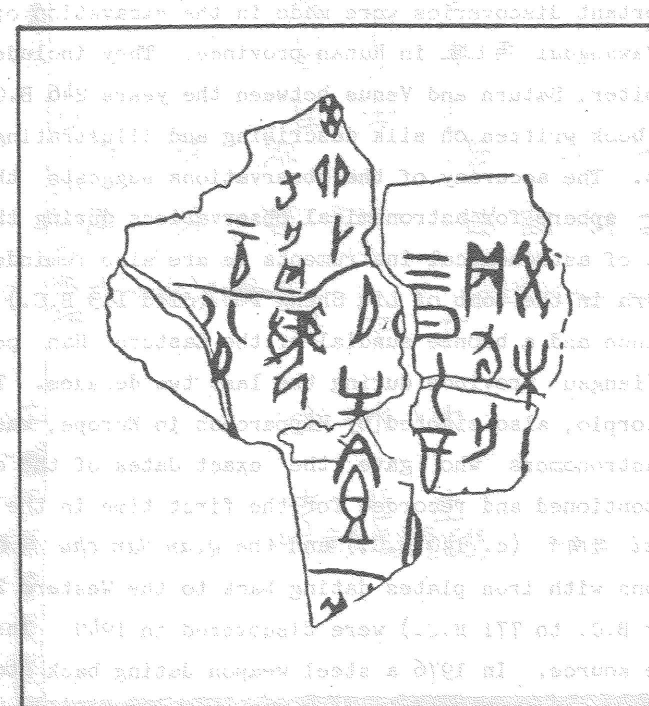
the 5th millennium B.C., this culture showed evidence of agriculture, animal husbandry, weaving and sewing, and fishing and hunting. The most interesting discovery in Banpo is perhaps the many types of pottery, some with patterns suggesting an ancient form of the Chinese script and numerals.[7] Banpo represented an early phase of the Yangshao 仰韶 culture, which existed in China from the 6th millennium B.C. until about 3000 B.C. Other phases of this culture have been found in Gansu, Shaanxi, Shanxi, Henan and Shandong provinces. This culture is characterised by its red painted pottery.

Rice grains were discovered in 1973 at the Hemudu 河姆渡 site in Zhejiang province, which dated back to the 5th millennium B.C. The Hemudu culture and other cultures developed in China parallel to the Yangshao culture. Then between the 4th and the 3rd millenia B.C. was the Longshan 龍山 culture, first discovered in 1928 at Shangdong province, and has since been found distributed along the lower and upper reaches of the Yellow River. This culture is characterised by its white and black pottery, most of which were made on the potter's wheel. In 1974 the Erlitou 二里頭 culture was discovered in Henan province. Bronze vessels of this culutre, dating back to about the year 1700 B.C. have also been discovered, indicating that by that time China was already in the Bronze Age. According to Chinese written records there was a Xia 夏 dynasty between the 21st and the 16th centuries B.C., but so far there has not been any archaeological evidence. Chinese archaeologists are now searching for the Xia culture, and Erlitou is one of the sites where they are hoping to make their finds.

Excavations carried out first at Anyang 安陽 and later at Zhengzhou 鄭州 in Henan province have substantiated the existence of the Shang 商 dynasty (16th to 11th centuries B.C.). Many bronze artifacts, foundry sites and proto-porcelain wares have been discovered at the various sites. At the ruins in Anyang were found the remains of the capital of the last Shang kings. This later period of the Shang dynasty is known as Yin 殷 (14th to 11th centuries B.C.). Besides bronze artifacts, gold, jade, pottery, shell objects, wooden artifacts with traces of lacquer, traces of silk fabric and even a chariot, the most important finds must be the oracle bones. These were carapaces of tortoises and shoulder-blades of oxen used by the Yin kings for divination. They contain the oldest known Chinese scripts before the discoveries of the Banpo pottery markings as well as the oldest Chinese written records. In them we can find records of eclipses, novae and names of stars and some of the constellations.[8] They also indicate that the Yin people were already using a luni-solar calendar, where one year contained 12 moons or lunar months of either 29 or 30 days each, and once every two or three years a 13th moon or intercalary month (*runyue* 閏月) had to be added. For naming the days, and at that time probably also the lunar months, a combination of two cycles, one of 10 ordinals called the 'celestial stems' (*tiangan* 天干) and the other of 12 ordinals called the 'terrestrial branches' (*dizhi* 地支) were used. The combination formed a sexagenary cycle. The oracle bones also show that the Yin Chinese were already using the decimal place-value system in mathematics.[9]

When we come to the Western Chou (11th century B.C.-771 B.C.) period we can find many beautiful bronze vessels and proto-porcelain wares. Many of the former carry inscriptions. Some astronomical data are found in two of the earliest Chinese books, namely the *Shujing* (*Book of Documents*) and the *Shijing*, both containing material ranging from about the 10th to the 5th century B.C. The earliest sighting of Halley's comet in the year 613 B.C. is found in the *Chunqiu* (*Spring and Autumn Annals*) which contains also records of solar and lunar eclipses, meteor streams and other comets. In the 5th century B.C. the Chinese were using the "Quarter-Remainder Calendar" (*sifenli* 四分曆) adopting their knowledge of $365\frac{1}{4}$ days in 1 tropical year and 237 lunations in 19 tropical years. From the *Zhouli* 周禮 (*Records of the Rites of Zhou*) we know that official star clerks were already employed by the Zhou kings to observe both astronomical and meteorological phenomena and to make astronomical interpretations from these observations.

In 1978 a wooden box bearing the names of all the 28 lunar mansions (*xiu* 宿) and dating back around 439 B.C. was unearthed from a tomb in

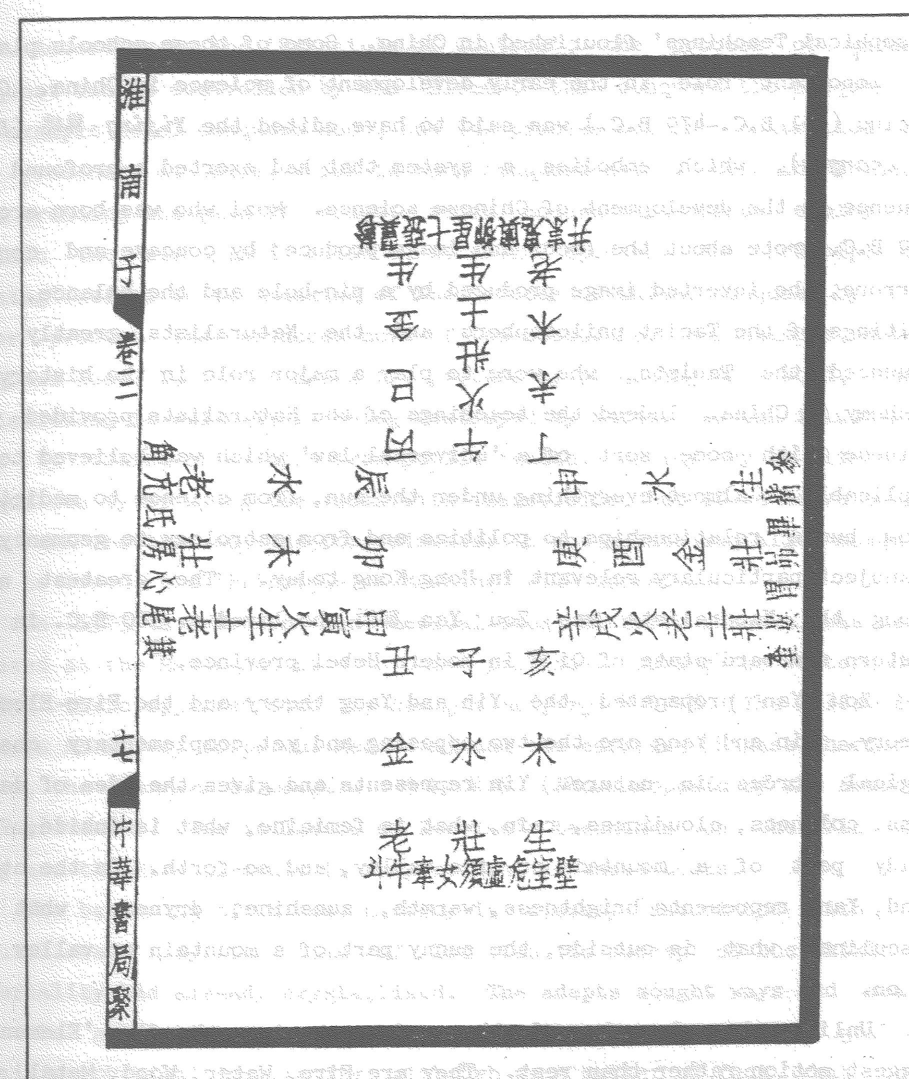


An oracle bone record of a lunar eclipse of 2 September 1297 B.C.

Suixian, Hubei province.[10] The earliest star catalogue is said to be due to a personage of the Shang dynasty, the astrologer Wu Xian 巫咸, of whom we know very little. Between about 370 B.C and 270 B.C. Gan De 甘德 and Shi Shen 石申 produced their own star catalogues. Although all the three original catalogues are now lost, fragmentary quotations from them still exist in many old astronomical texts. Chen Zhuo 陳卓 (fl. c. A.D. 310) later constructed a star map based on these catalogues. In 1973 many important discoveries were made in the excavation of a Western Han tomb in Mawangdui 馬王堆 in Hunan province. They include the ephemerides of Jupiter, Saturn and Venus between the years 246 B.C. and 177 B.C. and a book written on silk describing and illustrating comets of various shapes. The accuracy of the observations suggests the use of the armillary sphere for astronomical observations during that period. On the subject of astronomical instruments we are also reminded of the bronze clepsydra in the tomb of Liu Sheng 劉勝 (died 113 B.C.) discovered in Hubei province and a bronze sundial of the Eastern Han period discovered in Jiangsu province during the last two decades. The nova of 134 B.C. in Scorpio, also sighted by Hipparchus in Europe, was observed by Chinese astronomers who gave the exact dates of the occurrence. Sunspots are mentioned and recorded for the first time in the world in the *Huai-nanzi* 淮南子 (c. 140 B.C.) and the *Qian Han shu* 前漢書.

Two weapons with iron plates dating back to the Western Zhou period (11th century B.C. to 771 B.C.) were discovered in 1949. The iron came from meteorite source. In 1976 a steel weapon dating back to the 6th century B.C. was excavated in Changsha, showing that China had already entered the Iron Age by that time. Many iron artifacts of the 5th century B.C. have been found in Jiangsu and Henan provinces more recently. Although iron seems to have been known earlier in Europe than in China, it is interesting to note that the Chinese knew about the making of cast iron at least by the 5th century B.C. soon after iron was known to them, in contrast with the much later development of cast iron technology in Europe.

Between the 6th and 4th centuries B.C. the 'Hundred Schools of Phi-



A page from the Western Han book *Huai-nanzi* that gives the complete list of the 28 lunar mansions. The list is now antedated by recent archaelogical discoveries.

losophical Teachings' flourished in China. Some of these schools played an important role in the early development of science in China. Confucius (551 B.C.-479 B.C.) was said to have edited the *Yijing* 易經 (*Book of Changes*), which embodies a system that had exerted a profound influence on the development of Chinese science. Mozi who was born around 479 B.C. wrote about the focus and image produced by concave and convex mirrors, the inverted image produced by a pin-hole and the balance. The writings of the Taoist philosophers and the Naturalists greatly influenced the Taoists, who were to play a major role in the history of alchemy in China. Indeed the teachings of the Naturalists provided the Chinese with some sort of a 'universal law' which was believed to be applicable to almost everything under the sun, from science to medicine, from human relationships to politics and from astrology to geomancy — a subject particulary relevant in Hong Kong today. The greatest name among the Naturalists was Zou Yan 鄒衍 who lived c. 300 B.C. in the eastern seaboard state of Qi 齊 in modern Hebei province.[11]

Zou Yan propagated the Yin and Yang theory and the Five-Element theory. Yin and Yang are the two opposing and yet complementary cosmological forces in nature. Yin represents and gives the idea of darkness, coldness, cloudiness, rain, what is feminine, what is inside, the shady part of a mountain or of a valley, and so forth. On the other hand, Yang represents brightness, warmth, sunshine, dryness, what is masculine, what is outside, the sunny part of a mountain or valley and so on.

Unlike the elements of the modern chemist, the five 'Elements' suggest motion rather than rest. They are Fire, Water, Wood, Metal and Earth. The Chinese have an 'Order of Mutual Production', in which Fire produces Earth, Earth produces Metal, Metal produces Water, Water produces Wood, and Wood produces Fire and an 'Order of Mutual Conquest', whereby Fire conquers Metal, Metal conquers Wood, Wood conquers Earth, Earth conquers Water, and Water conquers Fire. From these two orders the Chinese have also worked out two principles, namely the 'Principle of Control' (*xiangzhi* 相制) and the 'Principle of Masking' (*xianghua* 相化). According to the 'Principle of Control', the process of mutual conquest can be controlled by the 'Element' that conquers the conqueror. For example Metal conquers Wood, but the process can be controlled by the presence of Fire, which in turn conquers Metal. Here the Chinese were treading the path of thought which modern scientists employ to explain the ecological balance of animal species. The 'Principle of Masking' refers to the masking of the process of mutual conquest by another process that produces more of the substrate. For example, Metal conquers Wood, but Water masks the process by producing more Wood, thus replenishing it while it is being destroyed by Metal. We can illustrate this by taking an example from public health. We may try to eliminate mosquitoes by spraying the rooms with insecticide, but if we leave empty tins and bottles outside for rainwater to accumulate and allow mosquitoes to breed, the 'Principle of Masking' will operate.

In 1973 a Western Han medical book, hitherto unknown, was discovered at the Mawangdui site in Hunan province. During the Western Han period there appeared also the *Huangdi neijing* 黃帝內經 (*The Yellow Emperor's Manual of Corporeal Medicine*) and the earliest Chinese pharmacopoeia, the *Shennong bencaojing* 神農本草經 (*Pharmacopoeia of the Heavenly Husbandman*). The influence of Zou Yan's teachings on the Yin and Yang and the Five Elements is very evident in these books.

The beginning of Chinese alchemy is closely associated with the Naturalists. By the time of Zou Yan the concept of the elixir of immortality had already crystallised. The adepts sought ways and means to make gold which they thought was a first step towards their goal of attaining physical immortality, although as a matter of fact, what they succeeded in doing was to make imitation gold. During the 3rd century B.C. the first Qin emperor, Shihuangdi 始皇帝 sent several expeditions to the eastern sea in search of the medicine of immortality. In the 2nd century B.C. Liu An 劉安 produced a book on magic and alchemy. By that period the making of fraudulent gold was so common in China that an imperial edict was issued in 144 B.C. to ban it.[12]

China was geographically separated from its western neighbours by high mountain ranges, deserts and seas. It was only during the 2nd century B.C. that China established official contact with its western neighbours. During the Qian Yuan 乾元 period (140 B.C.-134 B.C.) Zhang Qian 張騫 was sent by the emperor on an official mission to the west. After visiting Bactria and Sogdiana he returned to China in 126 B.C. In 120 B.C. the Chinese emperor established for the first time an embassy in the west. Thus formal contact with the west first took place through the Old Silk Route. Zhang Qian also reported that he noticed the existence of a trade route between Sichuan and India via Yunnan and Burma or Assam. Diffusion of scientific knowledge between China and its western neighbours before the time of Zhang Qian would be quite difficult although not altogether impossible. One cannot jump to conclusions on the basis of casual observations. For example, the resemblance of the Egyptian and the Chinese pictogram for sun or the fact that the Mesopotamian and the Chinese both use the luni-solar calendar taken by themselves alone can hardly justify the diffusion theory. One needs to understand both systems fully before propounding any hypothesis. Recent archaeological discoveries tend to favour independent development of science at its early stage in China in general.

Between the Han and the Song dynasties China continued to make progress in alchemy, astronomy, geography, physics, mathematics, medicine and technology. Cultural contact between China and its eastern neighbours, namely Korea and Japan and also between China and Annam, had already taken place by the time of the Han dynasties. Science came in the wake of literature, philosophy and religion. The Chinese calendars were adopted in all these countries and astronomical observations made in these countries were all conducted after the fashion of the Chinese. Chinese influence was particularly strong during the time of the Tang dynasty (A.D. 618-906). In fact, before the impact of science from Europe in the 18th century, science and medicine in East Asia was predominantly Chinese in character. Even today we can find in Kyoto, for example, Japanese physicians practising the traditional form of Chinese medicine, known in Japan as Kampō 漢方 and throughout Japan we can buy

from the book stores a copy of the Chinese luni-solar calendar, still used by farmers and astrologers in Japan today.

Meanwhile China's contact with its western neighbours also increased. Buddhism came from India during the time of the later Han dynasty. By the time of the Tang dynasty merchants, both Chinese and Arabs, were plying between China and Arabia, stopping at the ports of call along the sea route linking China to West Asia and Egypt. During the 8th century the Tang capital Changan 長安 (modern Xian) was probably the most busy and fashionable cosmopolitan in the world, where Arabs, Indians, Japanese, Koreans, Persians, Syrians and other nationalities came together. Even the Nestorians had established themselves there. Scientific and technological knowledge flowed in both directions. In Lecture III we shall look at the development of science in other parts of the Old World, including China, that helped bring about the Renaissance, and finally in the last lecture of this series we shall see how China responded to the coming of modern science.

NOTES

1. See Jean Fernal, *De Abditis Rerum Causis* (1548) and the more recent work on Jean Fernal by Sir Charles Sherrington, *The Endeavour of Jean Fernal* (Cambridge, 1946). This passage has been often quoted; see for example, Baos, Marie, *The Scientific Renaissance, 1450-1630* (New York, 1962), p. 17; Yabuuchi, Kiyoshi, *Chūgoku Kodai no Kagaku* (Tokyo, 1964), p. 155; Ho Peng Yoke, *The Birth of Modern Science in China* (Kuala Lumpur, 1967), p. 5.
2. See Joseph Needham, *Science and Civilisation in China*, vol. 4, part 1 (Cambridge, 1962), pp. 229-328 for a detailed account on the Chinese invention of the magnet.
3. Gilbert's great work, the *De Magnete*, was published in 1600.
4. See Cheng Te-k'un, *Archaeology in China*, vol. 3 (Cambridge, 1963), pp. 222-223.
5. The gunpowder epic will be fully discussed in Joseph Needham,

Science and Civilisation in China, vol. 5, part 1 (in press).
6. See, for example, Ho Ping-ti, *The Cradle of the East* (Hong Kong, 1975, London and Chicago, 1976) and Chang Kwang-chih, *Early Chinese Civilization* (London and Cambridge, Mass., 1976) on early civilisation in China.
7. Further light is shed by more pottery markings discovered at the Jiangzhai site near Banpo village in 1972.
8. A comprehensive list of novae and comets observed in China is given in Ho Peng Yoke, "Ancient and Mediaeval Observations of Comets and Novae in Chinese Sources", *Vistas in Astronomy*, vol. 5 (London, 1962), pp. 127-225. This list will be up-dated by the new catalogue *Zhongguo gudai tianxiang jilu zongbiao* 中國古代天象記錄總表 recently prepared by a team in the Peking Astronomical Observatory.
9. On the use of the decimal place-value system see Joseph Needham, *Science and Civilisation in China*, vol. 3 (Cambridge, 1959).
10. The nucleus of the 28 mansions can be found in the Shang oracle bones and at least 8 out of these lunar mansions appear in the *Shijing* although they come under different and archaic names. However, hitherto the earliest mention of all the complete lunar mansions in historical records was believed to be in 239 B.C. by Lu Buwei 呂不韋 in the *Lushi chunqiu* (*Master Lu's Spring and Autumn Annals*).
11. A recent study says that Zou Yan was antedated by Boyang Fu 伯陽父 also known as Shi Bo 史伯 who associated two earthquakes of 780 B.C. and 773 B.C. of his time with the operation of the Yin and Yang and the Five Elements. See Zuo Yihuan, 'Yin-Yang wuxingjia di xianquzhe Boyang Fu' 陰陽五行家的先驅者伯陽父, *Fudan xuebao*, 1980, 1: 97-100.
12. For further details see Joseph Needham, *Science and Civilisation in China*, vol. 5, part 3 (Cambridge, 1976).

LECTURE II

SCIENCE IN THE ANCIENT WORLD II: THE NEAR EAST AND SOUTH ASIA — CONTINUOUS INTERACTION

From history we learn that the most important cultural patterns of the human race first crystallised in some great river basins in the northern hemisphere, e.g., the Nile in Egypt, the Euphrates and the Tigris in Mesopotamia, the Indus and the Ganges in India, and the Yellow River and the Yangzi in China.[1] As we have already seen very briefly the development of science in traditional China, we shall now turn our attention to the first three of these culture areas.[2]

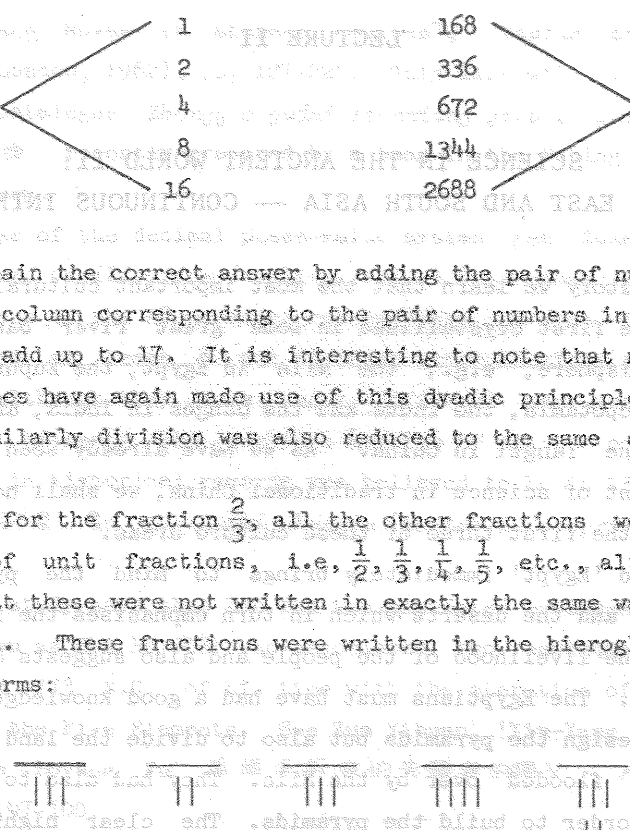
The world 'Egypt' immediately brings to mind the pyramids, the river Nile, and the deserts which in turn emphasises the importance of the Nile to the livelihood of the people and also suggests a clear and cloudless sky. The Egyptians must have had a good knowledge of geometry not only to design the pyramids but also to divide the land again every time it was flooded over by the Nile. They had also to be very good engineers in order to build the pyramids. The clear night sky would stimulate observation of the stars.

The oldest mathematical texts known in existence are the *Golenishev papyrus* (now in Moscow) and the *Rhind papyrus* (now in London). They represent the state of mathematical knowledge in Egypt in about the 19th century B.C. Ancient Egyptian arithmetic is characterised by its procedure, which is essentially additive in nature, and by its use of unit fractions, i.e., fractions with unity as numerator. Let us see how an ancient Egyptian would multiply a number, say 168, writing the number in the modern form. If he wished to multiply this number by 2 he would simply double the number by adding the same number to itself. If he wished to multiply 168 by another number, say 17, he would repeat the process of doubling as follows:

	1	168	
	2	336	
Total 17	4	672	Total 2,856
	8	1344	
	16	2688	

He would obtain the correct answer by adding the pair of numbers in the right-hand column corresponding to the pair of numbers in the left-hand column that add up to 17. It is interesting to note that modern computing machines have again made use of this dyadic principle of multiplication. Similarly division was also reduced to the same additive process.

Except for the fraction $\frac{2}{3}$, all the other fractions were expressed in terms of unit fractions, i.e, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, etc., although we must remember that these were not written in exactly the same way as they are now written. These fractions were written in the hieroglyphics in the following forms:



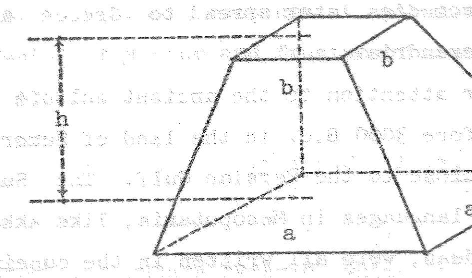
$\frac{2}{3}$ $\frac{1}{2}$ $\frac{1}{3}$ $\frac{1}{4}$ $\frac{1}{5}$

In geometry the Egyptians gave the area of a triangle as half the side

multiplied by the base, which we know is only approximately true for a thin triangle. They took the ratio of the circumference to the diameter of a circle, i.e. π, to be 3.16. The surveyors could make right-angled triangles by using ropes divided by knots with lengths in the ratio of 3:4:5. The exact volume of the frustum of a square pyramid is given by the formula:

$$V = \frac{h}{3}(a^2 + ab + b^2)$$

where h is the height, and a and b the lengths of the two sides at each end of the frustum respectively.



The Egyptian year was based entirely on the apparent movement of the sun, i.e., it was a solar calendar. At first the year consisted of 360 days divided into 36 *decans* of 10 days each. Three *decans* also made a month. Later on, a holiday period of 5 days was added, giving rise to a civil year of 365 days. The Egyptian also knew about the Sothic cycle, i.e., after every single year the rising of Sothis (i.e. Sirius) would be $\frac{1}{4}$ day late and after 4 x 365, i.e., 1,460 years *Sothis* would appear again in the same place at the same time in the same day of the year. In 45 B.C. Julius Caesar introduced the Sothic year of $365\frac{1}{4}$ days in Rome. This was the Julian Calendar, which had come into use for 17 centuries in Europe before it was replaced by the Gregorian Calendar. Another Egyptian contribution to our modern culture is the division of the day and night into 24 hours, although the Egyptian time interval was not of equal length and we had to wait for Greek astronomy to give us equal time interval for the hours.

Ancient Egypt was quite advanced in medicine. The oldest medical treatise extant, the Smith papyrus, dated back to about the year 2000 B.C. The practice of embalming the dead would require some elementary knowledge of anatomy. The Egyptians could trace the larger organs of the body, but without being able to explain their function properly. Surgery was practised as early as 2500 B.C. Physicians were trained as specialists. There were bone-setters for fractures, and occulists for disease of the eye. However, mental disorder was treated by the exorcists, who would employ charms, incantations, etc. to dispel the evil spirits believed to be responsible for the ailment. The art of dispensing drugs and essence in ancient Egypt attained a high degree of excellence. Many Egyptian remedies later spread to Greece and then to Western Europe through Alexandria.

We shall now turn our attention to the ancient culture in Mesopotamia which developed before 3000 B.C. in the land of Sumer between the Euphrates and the Tigris close to the Persian Gulf. The Sumerian language and all subsequent languages in Mesopotamia, like Akkadian, Babylonian, Assyrian and Chaldean, were all written in the cuneiform script on soft fresh clay which was then baked by a fire or under the sun. The oldest cuneiform tablets, dating from about 3000 B.C., were found in the Red Temple at Warka in south Babylonia.

In mathematics the Sumerians employed a rather peculiar combination of a decimal (i.e, in 10 and powers of 10) and a sexagenary system (i.e, in 60 and powers of 60). Two separate signs were used, i.e. ∇ and $<$. ∇ could mean 1, or 60, or 60^2, etc. i.e., $\nabla = 60^n$ where n = 0, 1, 2, 3 .... $<$ could mean 10, or 10 x 60, or 10 x 10^2, etc. i.e., $< = 10 \times 60^n$. Babylonian cuneiform tablets contain many kinds of numerical tables, e.g., of multiplication, squares, cubes and reciprocals. A characteristic of Mesopotamian mathematics is the common use of the number 60. This practice has come down to us in the division of the circle into 360°, 1° into 60' and 1' into 60", and the division of the hour into 60 minutes and the minute into 60 seconds.

The Babylonians worked out a close fractional approximation for $\sqrt{2}$, which reappeared in the Hindu *Sulva-Sūtras* during the 3rd or 4th century B.C. Although they did not know about algebraical notations, the Babylonians could solve some problems on compound interest, linear equation with more than one unknown quantity, quadratic equations, and even some cubic equations. Their solution of equations was by a series of numerical steps without arriving at a general solution. They were also aware of the identity $(a + b)^2 = a^2 + 2ab + b^2$.

In geometry the Babylonians could measure the rate of rectangles, right-angled triangles and isosceles triangles, and had some knowledge of the Pythagorean theorem. They knew that the angle subtended by the diameter on the circumference of a semi-circle is a right-angle. They could find the volumes of rectangular parallelepiped, right circular cylinder, frustum of a cone and frustum of a square pyramid. They gave, for example, the formula:

$$V = [h (\frac{a + b}{2})^2 + \frac{1}{3} (\frac{a - b}{2})^2]$$

for the frustum of a square pyramid, which is similar to that given by the Egyptians, but in a more elaborate form. The Babylonians gave two values for π, a rough value 3, and a closer approximation $3\frac{1}{8}$.

In astronomy the Babylonian calendar was based on the lunar and the solar cycles. The year in this luni-solar calendar consisted of 12 lunar months of either 30 or 29 days each. The average length of 12 lunar months would therefore be $29\frac{1}{2} \times 12 = 354$ days, which was shorter than the solar year of about $265\frac{1}{4}$ days. To harmonise the lunar cycle and the solar cycle, the Babylonians introduced an extra lunar month called the intercalary month, whenever it was found necessary. There would be about 384 days in a year with an intercalary month. The Babylonian calendar was adopted by the Hebrews and then later by the Greeks and the Romans before 45 B.C. when it was replaced by the Julian calendar. The Babylonian month was divided into weeks of 7 days each. However, the week days were not continuous from one lunar month into another, but the first day of the month always began with the first day of the week. It was not until the 1st century B.C. that our present continuous seven-day week system was adopted in Europe.

The Babylonians made careful observations on the planets. They found the synodic period of Venus to be 584 days (modern value 583.92 days). They concluded that the moon and the planets did not move far away from the ecliptic. They compiled a list of eclipses dating from 747 B.C. and the data contained in this list was later used by the Greek astronomer Ptolemy (fl. A.D. 140). In the year 343 B.C. Cidenas discovered the precession of the equinoxes. Also on the basis of their astronomical observations the Babylonians developed a scheme of astrology attempting to predict the course of human affairs from the stars. Hence the growth of judicial and horoscopic astrology. The high priests in Babylonia secured real power over the minds of the people with their knowledge of astrology and were always held in high esteem. This stimulated the study of astrology and indirectly astronomy. We must remember that in ancient and mediaeval Europe the word 'astronomy' included both astrology and what we now call astronomy.

In biology the Babylonians were familiar with the names of many animals and fish. There is evidence of some sort of crude classifications of animals and plants. However, the Babylonians seemed to know less anatomy than the Egyptians. They regarded the liver as the most important organ in the body, being the seat of life and emotions itself. Later they regarded the heart as the seat of intellect. Babylonian medicine was full of magic. The physicians used prayers, charms and talismans besides medicine to cure the sick. There were surgeons who would operate with bronze lancets, but unlike the physician, the surgeon would be awarded by law when his operation succeeded, but be punished accordingly should it fail.

Science in Egypt and Mesopotamia exerted considerable influence on the early stage of Greek science. The Greeks came to Greece at about 1400 B.C. and extended themselves as far east as the western coast of Asia Minor and as far west as the southern part of Italy and Sicily. The seed of Greek science first germinated during the 6th century B.C.

at Miletus, a port in Ionia along the western coast of Asia Minor. Thales (c. 624 B.C.-565 B.C.), who had travelled before to Egypt and Mesopotamia, founded the philosophical school of Miletus. He generalized some of the geometry he learned in Egypt, making observations and drawing conclusions from them. We owe him the first conception of the deductive method in mathematics and also the first assumption of a natural universe which could be explained by rational inquiry. Thales regarded Water as the essence of all things, Anaximenes (c. 570 B.C.-526 B.C.) considered Air to be most important and called it *pneuma*, while Heracleitus (c. 540 B.C.-475 B.C.) took Fire to be most important. Thus the concept of Element was first developed in Ionia. The earliest concept of the atom was also developed in Ionia by Democritus (c. 470 B.C.-400 B.C.).[3]

One of the Ionians, named Pythagoras (b.c. 582 B.C.) went to south Italy and founded the Pythagorean School. Geometry was further developed here, and so was the so-called Four-Element theory, represented by Air, Water, Fire and Earth. The earth was believed to be spherical in this school. One of the Pythagoreans, Philolaus of Tarentum (c. 480 B.C.-400 B.C.) said that the sun, the moon, the earth, the five known planets, and the sphere of stars were all moving round a central fire and introduced a 'counter-earth' to make up the perfect number 10.

Some Ionian scholars also went to Athens in the mainland of Greece itself. Among them was Hippocrates (c. 460 B.C.-377 B.C.), the famous physician, who has been called "the father of medicine" for the inductive method he used to study medicine. Towards the end of the 5th century B.C. Greece came under the influence of the teaching of Socrates (470 B.C.-399 B.C.) who saw knowledge as a virtue but was not favourable in his attitude towards science. He was succeeded by Plato (427 B.C.-347 B.C.) who had great interest also in mathematics and astronomy. He set his disciples to find out rules to reduce the movements of the heavenly bodies into a system of spheres and circles. Thus he made astronomers in Europe after him go round in circles for the next two thousand years until the time of Kepler. Plato also described the five regular solids, now known as 'Platonic Bodies' and used them to represent the forms of the Five Elements and the heavens. As a scientist, however, Plato was overshadowed by one of his many disciples, Aristotle (c. 384 B.C.-322 B.C.) who founded the Peripatetic School of Philosophy at Athens after 336 B.C. The climax of his career lied in this school and it lasted only 12 years. Having written on a wide range of subjects, from philosophy to science and from ethics to politics, he became the greatest collector and systematiser of knowledge in the ancient world. His teachings on physical science had a profound influence in Europe until the Renaissance.

The Greek empire was divided after the death of Alexander the Great in 323 B.C. One of his generals, named Ptolemy, seized Egypt and made Alexandria not only his capital but also an important seat of learning. Among the first to join the Alexandrian Academy was Euclid (c. 330 B.C.-275 B.C.) who came from Athens and was probably a disciple of Plato. His *Elements of Geometry* had reduced all previous writings on the same subject to unnecessary reading matter. The first half of the 3rd century B.C. saw the rise of mechanics. This was due to none other than Archimedes (287 B.C.-212 B.C.). The third great mathematician of the same century was Appollonius of Perga (c. 260 B.C.-200 B.C.), well known for his study of conic sections. The greatest astronomer of ancient Europe was Hipparchus (c. 192 B.C.-120 B.C.). He is remembered for his careful observations of the stars, his sighting of a nova (new star) in the constellation Scorpio in 134 B.C. and for the theory of 'epicyclic motion' and 'excentric motion' put forward by him to explain the movements of the planets.[4]

Egypt became part of the Roman empire by about 50 B.C. and by 30 B.C. Alexandria was administered from Rome. The heyday of creative science in Alexandria had ended, but the tradition of Greek science was continued by a number of writers, such as Dioscorides (c. A.D. 40-c. A.D. 90), Claudius Ptolemy (fl. A.D. 140), Diophantus (fl. c. A.D. 180), Galen (A.D. 130-A.D. 201) and Pappus (fl. c. A.D. 300). Claudius Ptolemy's name is often associated with his *Almagest*, which had become

one of the most influential scientific books in history. In this book he visualises a spherical earth at the centre of the universe. Next to the earth are the 3 spheres of elemental Water, Air and Fire. Then come the crystalline spheres of the heavens of the moon, Mercury, Venus, the sun, Mars, Jupiter, Saturn and the firmament to which the stars are supposed to attach. Finally, comes the sphere of *primum mobile*, which is supposed to produce the motion of all the celestial bodies. Diophantus wrote on algebra, but his works were known in Europe only in 1575, but by then algebra in Europe had already progressed far beyond the point where he left off. Pappus was essentially a geometrician, while Dioscorides was a botanist, pharmacologist and physician. Galen was the greatest Greek anatomist and physiologist of classical times. The ingenious physiological system evolved by him was accepted by the Western world for over one thousand years until the time of Vesalius in the 16th century. The arrival of the Christians marked the fall of the Athenian school in the 5th century. European learning had already entered the Dark Ages. In the 7th century the Muslims conquered Alexandria and the Alexandrian Academy came to an end.

While Europe is taking a long slumber in the Dark Ages let us cross over to India and take a short glimpse of the development of science in that sub-continent. The earliest Indian contribution to science lies in the field of medicine.[5] According to Hindu tradition, in the time of the Buddha (6th century B.C.) there were 2 great schools of India, one in the east, at Kāsi (or Benares) and one in the west, at Takesilā (or Taxila). Susruta, the surgeon was teaching in the former and Atreya, the physician, in the latter. Modern scholars disagree among themselves regarding the exact dates of Susruta and Atreya and have placed their limits between the 6th century B.C. and the 5th century A.D., an example of the difficulties encountered in studying Indian history. The earliest Hindu works on astronomy are the *siddhāntas*. There were 5 of them, e.g. the *Sūrya-Siddhānta*, the *Paitāmaha-Siddhānta*, the *Vāsishtha-Siddhānta*, the *Paulisa-Siddhānta* and the *Romaka-Siddhānta*. Of these only the *Sūrya-Siddhānta* is extant in its original form. The text of the *Sūrya-Siddhānta* itself says that it was written by Sūrya, the Hindu Sun-God. However, much of its astronomical theories seem to be of Greek origin, although much of the Hindu astronomical lores are also preserved. The most important feature of this work is the use of sines (*jyā*) instead of chord. It also gives the earliest mention of a versed sine (*utkra mājya* or *utra madjyā*). A tentative date of the first half of the 5th century A.D. has been given to the *siddhāntas* because the Greek influence appears to be of a post-Ptolemaic nature and because they were mentioned by Āryabhata (b. 476?).[6]

Āryabhata was the first of a number of great Indian mathematicians. In 499 A.D. he wrote an important mathematical treatise called the *Āryabhatīya*, which deals with trigonometry, numeration by tens up to 10^8, plane and solid numbers, a rule for finding square roots, general solution of indeterminate linear equations, quadratic equations, sum of arithmetic series, etc. and gives a value $\pi = 3.1416$. At about the same time as Āryabhata lived the great Hindu astronomer, mathematician and poet, Varāhamihira, who wrote the *Pancasiddhāntika*, a book of astronomy and astrology that contains also some trigonometrical rules. Brahmagupta (b. 598?), the great 7th century Hindu mathematician, wrote the *Brāhmasphuta-siddhānta*, which he based on the *Sūrya-siddhānta* and the *Āryabhatīya*. In about the 9th century lived Mahavira the Learned, who wrote a treatise to improve upon the work of Brahmagupta. About this time there appeared also the *Bakhshāli MS*, a book on arithmetic and algebra but of uncertain date and origin. In the 10th century flourished the Hindu mathematician Srīdhara, who wrote the *Ganitāsara*, a book dealing with series, squares, cubes, roots, interest, partnership, mensuration and shadow measurement. Finally, in the 12th century flourished Bhaskara (1114-c. 1185), who is noted for his *Lilāvati*, a book on arithmetic and mensuration. He also wrote the *Bija Ganita*, a book of algebra.

The main contributions by the Indians to modern science are their algebra, their numerals (often wrongly called 'Arabic numerals'), their symbol for zero, and their trigonometrical tables. While leaving their westward diffusion to the next lecture, we shall take a brief look at the mutual exchange of scientific knowledge between India and China.

As mentioned in Lecture I above, contact between China and India was possibly made before the 2nd century B.C.. However, written records of cultural exchange are only available from the 3rd century A.D. when many scholars from India and Kashmir went to China by land and sea with the introduction of Buddhism to China. Chinese scholars and monks also went to India, for example the famous pilgrimage made between 399 A.D. and 411 A.D. by the Chinese monk Faxian 法顯 (334-420) and that made between 627 A.D. and 646 A.D. by Xuanzhuang 玄奘 (596-664). Mutual exchange of scientific knowledge took place as a result of cultural contact. Let us see a few examples.[7]

The *Paulisa siddhānta* gives a value of $\sqrt{10}$ for π, which is fascinating because the same value was given earlier in China by Zhang Heng 張衡 (78-139) in A.D. 130. This value was also repeated by Mahāvīra in the 9th century and Srīdhara in the 10th century. Still more interesting is the formula given by Mahāvīra for the segment of a circle in the form:

$$A = \frac{1}{2}s\ (c + s)$$

where A is the area, c the length of the chord, and s the sagitta. This formula is incorrect and it also appeared 600 years earlier in China in Liu Hui's 劉徽 commentary of the *Jiuzhang suanjing* 九章算經 .

We obtain more information from Chinese records from the Chinese end. Indian astronomical writings came to China during the Sui dynasty (A.D. 581-A.D. 618). At least one of these books, the *Boluomen Yinyang suanli* 婆羅門陰陽算曆 (*Brahminical Calculations of the Calendar*), went to Japan from China during the 9th century. The idea of the "Seven Luminaries" (Qi Yao 七曜) was introduced to China in A.D. 230 with the translation of the *Sārdūlakarna-Vadana* into Chinese. The Chinese lunar month was first divided into 3 decans (*xun* 旬) of 10 days each. Later on, when the week was introduced from the Iranian culture-area through c = chord

A = area of segment

d = diameter of circle

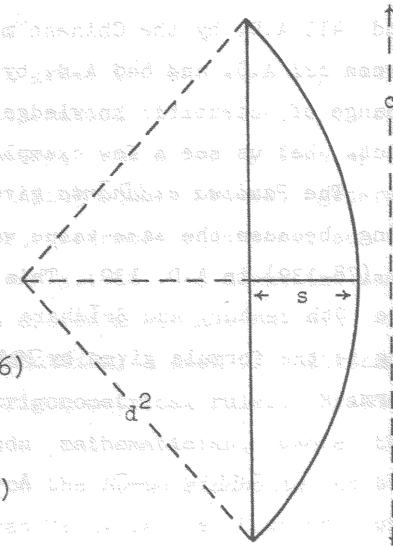
s = sagitta

$A = \frac{1}{2}s\ (c + s)$ Liu Hui (c.A.D. 250)

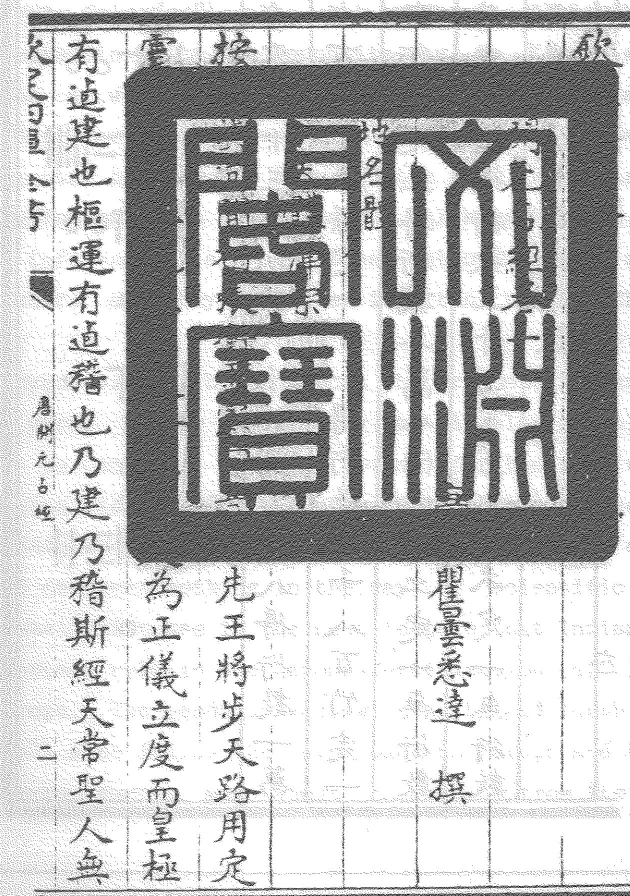
length of arc $= \frac{2s^2}{2} + c$ Shen Gua (1086)

$d^2(\frac{A}{2})^2 - d^3s - (d^2 - Ad)s^2 + s^4 = 0$

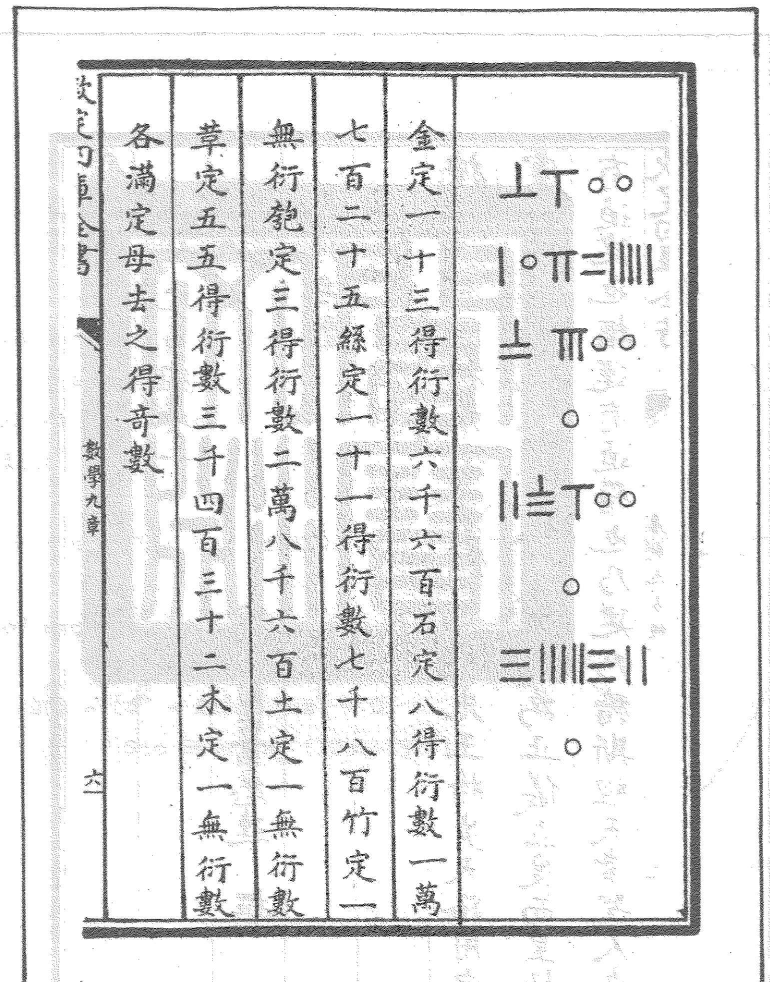
Guo Shoujing (1231-1316)



The arc and the segment in Chinese mathematics



First page of the 8th-century *Kaiyuan zhanjing* by the Hindu scholar Qutan Xida.


欽定四庫全書

金定一十三得衍數六千六百石定八得衍數一萬
七百二十五絲定一十一得衍數七千八百竹定一
無衍鮑定三得衍數二萬八千六百土定一無衍數
草定五五得衍數三千四百三十二木定一無衍數
各滿定母去之得奇數

數學九章 六

A page from Qin Jiushao's *Shusue jiuzhang* (i.e. *Shushu jiuzhang*, 1247) showing the first appearance of the circular symbol for zero in China.

India to China, the days of the week were named after the "Seven Luminaries". From China the names also went to Japan. Although the Chinese no longer use them, they are still retained in Japan today.

At about the 7th century an Indian calendar, the *Navagrāha* (*The "Nine Upholders Calendar"*) also went to China. Although it was never officially adopted in China, it found its way to Korea and was used officially for a while. The *grāha* ("Nine Upholders") are the "Seven Luminaries" (Sun, Moon, Mars, Mercury, Jupiter, Mars and Saturn) and two imaginary celestial bodies, the *Rahu* and the *Ketu*, which are supposed to be responsible for eclipses and comets. Although these 2 imaginery bodies had no influence at all on Chinese astronomy, they are considered as 'ominous stars' and they played an important role in Chinese astrology.

It is however agreed by many that the greatest Indian contribution to science is zero. By the 7th century the circular symbol for zero had already gone to Cambodia. The dot (*bindu*) for the zero was introduced to China by Qutan Xida 瞿曇悉達 (Gautama Siddhārtha) between 718 and 729 in his book *Kaiyuan zhanjing* 開元占經. Not only are we convinced that zero here does not mean nothing in the way of scientific contribution itself, we shall also see in the next lecture that Indian science also played an important role in the cross-fertilization of ideas between Arabia and Europe. The pendulum was swinging to and forth. In the next lecture we shall also follow the swing back to Europe and take it from the point where Europe was about to wake up from its long cultural slumber.

NOTES

1. One of the most recent reference books on all these ancient civilisations is Arthur Cotteral, *Encyclopedia of Ancient Civilisations* (New York, 1980).
2. For a general account on the history of science in these culture areas see for example George Sarton, *A History of Science* (Oxford,

1953) and O. Neugebauer, *The Exact Sciences in Antiquity* (Princeton, 1952, second edition 1952, reprinted New York, 1962).

3. For a general account of Greek science see for example Charles Singer, *Short History of Scientific Ideas to 1900* (Oxford, 1959) and Marshall Clagett, *Greek Science in Antiquity* (New York, 1963).
4. As mentioned in Lecture I above, this nova was observed by Chinese star clerks, who even recorded the exact dates of the occurrence. The *Qian Hanshu* ch. 26, p. 28a says, 'During the sixth month of the first year of the Yuanguang reign period (i.e., 22nd June to 21st July) a "guest star" (i.e., nova) appeared at the *Fang* lunar mansion (i.e. β, δ, and ρ Scorpius).
5. For Indian medicine see for example A.F.R. Hoernle, *Studies in the Medicine of Ancient India* (Oxford, 1907).
6. For Indian mathematics see for example B. Datta and A.N. Singh, *History of Hindu Mathematics: A Source Book* (Lahore, 1938), D.E. Smith and L.C. Karpinski, *The Hindu-Arabic Numerals* (New York, 1911), W.E. Clark, *The Āryabhaṭīya of Āryabhata* (Chicago, 1930) and G.R. Kaye, *Indian Mathematics* (Calcutta and Simla, 1915).
7. For further examples of Sino-Indian cultural exchange see Ho Peng Yoke, 'Indian Science in East Asia', *Proceedings of the International Conference-Seminar of Tamil Studies* (Kuala Lumpur, 1967), pp. 39-52.

LECTURE III

IMPACT OF ANCIENT CIVILISATIONS ON THE RENAISSANCE IN EUROPE

While Europe was, culturally speaking, fast asleep in the Dark Ages, the Arabs came into their own. In the first half of the 7th century they conquered the whole of Arabia, Persia, Syria and Egypt. After the destruction of the Alexandrian Academy some of the scholars fled to Constantinople, where they established the Byzantine school of learning, but the days of creative science were already past and gone. Through the northern coast of Africa the Arabs entered Spain in A.D. 711. The expansion of the Muslim came to a halt in A.D. 732 at the south of France. Until the time of the Renaissance in Europe the Arabs began to play a very remarkable role in history as the transmitter of science and technology.[1]

According to Arabian traditions, their scientific knowledge was first derived from the Nestorian physicians who attended their Caliphs at Baghdad. It was their skill in medicine that aroused the interest of the Caliphs, first in Greek medicine and then in Greek science. The Caliphs first decided to propagate Greek medicine in their vast Muslim empire. At about A.D. 800 the Caliph Hārūn al-Rashīd ordered Greek medical writings to be translated into Arabic. These translations were so successful that the next Caliph, al-Ma'mūn (reign 813-833) established a translation centre in Baghdad and sent commissions to Constantinople and India to acquire scientific writings. Many scholars were enlisted by him to translate Greek and Indian scientific works into either Arabic or Syriac.

Baghdad soon became a great centre of learning. Most of Aristotle's works were translated there, and so were many Greek writings on alchemy, botany, mineralogy and mechanics. Many Indian and Persian texts were also translated. Furthermore, learned Hindus also came all the way to Baghdad to present themselves to the Caliphs, some bringing along with them Indian scientific works. Thus, for example, the Hindu system of numeration, the sine tables and mathematical writings, such as the *Āryabhatiya* of Āryabhata, the *siddhānta* of Brahmagupta, and the *Lilāvati* and *Bija Ganita* of Bhaskara, were introduced to the Muslim world.

Among the many Muslim scientific writers was the eminent Persian mathematician al-Khwārizmī (fl. c. 850), who wrote the *Algebra,* which was based on the work of the Hindu mathematician Brahmagupta. It is here that the word 'algebra' first appeared in the mathematical sense. It came from the word 'al-jebr', meaning 'restoration', i.e., anything of the same magnitude may be added to or subtracted from both sides of an equation. All other Arabian works and early mediaeval European works on algebra were based on this book of al-Khwārizmī. Another book written by al-Khwārizmī was the *Arithmetic.*

Astronomy and astrology played an important part in the development of science in the Muslim world. In A.D. 829 the Caliph al-Ma'mūn built a fine observatory in Baghdad more splendid than the one previously built near Damascus under the Umayyad Caliphs (661-749). In Baghdad continuous astronomical observations were made and tables of planetary movements were constructed. The greatest of all Muslim astronomers was al-Battānī (877-929). He is remembered for his determination of the length of one degree of latitude on the earth's surface and for his introduction of the use of sines and tangents into trigonometry.

The 10th and 11th centuries were the golden age of Arabic literature. The greatest of all Arabic physicists, Alhazen (965-1038) lived during this period. He is remembered for his work on optics. He opposed the theory of Euclid and Ptolemy that the eye sends out visual rays, like tentacles, to the object of vision. The Greeks had a law of reflection which says that the angle of incidence is equal to the angle

of reflection. Alhazen added that both these angles must lie on the same plane. He also studied colour and optical illusion. The first detailed description and drawing of the human eye by a physician was made by him. Some of the modern names for parts of the eye originated from the Latin translation of his work, for example, the terms 'retina', 'cornea', 'aqueous humour' and 'vitreous humour'. Alhazen also recorded the semi-lunar shape of the sun's image during eclipses on the wall opposite a fine hole made in the window-shutter. This is the first-ever mention of the *camera obscura* since the reference to the action of the pin-hole by the Chinese philosopher Mozi in the 4th century B.C.

Significant contributions to the knowledge of alchemy were made by the Muslims between the 8th and the 11th centuries. The greatest name in Arabic alchemy was Jābir ibn Hayyan (c. 721-c. 817) who lived during the period made famous by the *Thousand-and-One Nights*.[2] To him alchemy was a matter for experimental research. He improved many laboratory methods such as crystallisation, distillation, evaporation, filtration, melting, and sublimation. Many chemical terms have come from him through Latin translations into modern usage, for example the words 'alcohol', 'alkali', 'antimony', 'borax', 'camphor', 'elixir', 'realgar', 'sal-ammoniac', and so on.

Jābir's views on the transmutation of metals had greatly influenced alchemy. He regarded mercury as the metal *par excellence,* because in the liquid form mercury showed that it had the least amount of impurities of the Earth Element. He next chose sulphur because of its gold-like yellow colour, its changeability and its combustibility. It is interesting to note here that mercury and sulphur were also the two most popular substances used by the Chinese alchemists several centuries before Jābir. For example, they are mentioned in the *Cantongqi,* the earliest book extant on alchemical theory written in A.D. 142 by Wei Boyang 魏伯陽.[3] Jabir regarded the different metals to be composed of different amounts of mercury and sulphur, and that if one could only mix the right proportion of mercury and sulphur one could produce gold. The Greeks were looking for a substance that could promote the transmutation of base metal into gold. This substance was believed to look like dry powder, and was known as *xerion,* from the Greek word for 'dry'. The Arabs called it *al-iksir,* from which came the 'elixir'. The elixir was

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