The History of Scientific Thought With Special Reference to Asia

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H. J. J. WINTER, M.SC., PH.D.
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Transaction No. 5

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By
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January 1951 **Price Re.** 1/-

THE INDIAN INSTITUTE OF CULTURE

TRANSACTIONS

The regular meetings of the Institute take place on Thursdays. Every alternate week a lecture is given under its auspices; on other Thursdays new publications are reviewed; both lectures and reviews are assigned to competent persons. The work done by speakers and reviewers deserves wider circulation and a more permanent shape. The Institute's day is still one of small beginnings and it is not, therefore, in a position to publish every lecture and review offered from its platform, though each is being steno graphically reported for the archives of the Institute. It has been found necessary to publish from time to time such of them as would help the public at large, particularly in India. The Institute exists to educate public opinion, to interest the public mind and enable it to gain a deeper insight into important problems of value to the individual in shaping his own mind and heart and in appreciating national and international problems. The platform of the Institute is broad and it allows those invited full freedom of expression. It is not responsible for the views of speakers and reviewers and does not always accept them as its own.

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The paper published here on "The History of Scientific Thought with Special Reference to Asia " was especially prepared by Dr. H. J. J. Winter for one of the recently introduced Discussion Meetings of the Institute, at each of which a paper sent by a distant friend is read and discussed. Bringing out as it does the universality of science, and how contributions of different lands and eras make possible further research elsewhere and in later times, it represents a valuable testimony to the fundamental unity of culture, the recognition of which the Indian Institute of Culture is trying to promote as the foundation of a united and peaceful world.

This paper, which we publish complete except for the bibliography which was appended, was read at a meeting on November 16th under the chairmanship of Sahityalankara Shri K. S. Nagarajan, B.SC. Among those who raised questions or otherwise contributed to the discussion which followed the reading of the paper were Shri C.B. Srinivasa Rao, Shri J. T. Pashupalaty, B.sc., Mr. J. O. Mackenzie and Dr. L. S. Dorasami, m.sc., ph.d., Honorary Secretary of the Institute.

The Chairman suggested a few more contributions of India to world science, in addition to the important ones conceded by Dr. Winter—the Indians having been the first to use letters of the alphabet as symbols to denote unknowns; their priority in the classification and detailed study of equations; their engineering skill in the construction of buildings, temples, bridges and reservoirs, including very ancient thousand-pillar assembly halls; and their early skill in surgery. He claimed for both the terms " geometry " and " trigonometry " a Sanskrit origin..

THE HISTORY OF SCIENTIFIC THOUGHT WITH SPECIAL REFERENCE TO ASIA

Broadly speaking, science has evolved in four stages, two Asian, two European, and these alternate, the East giving to the West, then the West giving to the East. So we find the Eastern Empires of Antiquity, in which science first flourished, bequeathing a legacy of technical skill and empirical rules on which Greece began to erect a great edifice of deduction and a system of knowledge. In their turn, the Greeks left their accumulated facts and, above all, their scientific method, to the Middle East, whence it traveled mainly with the Nestorians, on the decline of the Roman Empire. When the ‘Abbasid house rose to great power in Baghdad, enlightened patrons of knowledge in the Muslim world preserved the Greek legacy, augmented it with their own and with Hindu knowledge, and returned the precious heritage once more to Europe. Thus the Renaissance of science in Europe in the 16th and 17th centuries owed much to the preservation of scientific information by the Arabic scholars of mediaeval times who had kept the torch alight when Europe was wallowing in barbarism. The vast technology reared upon this foundation during the last three centuries is returning again to Asia to modify her life (to what extent who knows?) and the modern European methods of research are practiced in Asia's universities. Whereas Robert of Chester and other adventurous seekers after knowledge once came to Spain to know the science of the Arabs, today the traffic is one of young scientists from Asia, who come to the Western world to learn the processes and discoveries of the inductive method. We therefore see the universality of science. It is objective knowledge, the product of unbiased investigation . by men of many creeds and colors. Science respects no one except for his contribution.

Now European historians have, mainly through ignorance, thought of science as having only two phases: the Greek one, and that of the modern world, made possible through a revival of the Greek spirit. Admittedly these two phases are the greatest, but they would have been sadly weakened and delayed without the two Asian contributions. Of these latter we should like to know very much more, for their splendor is only now being revealed; but the progress of research into the earlier science of Asia is inevitably a slow accumulation of scattered data, some archaeological and some from manuscripts in many languages.

That Asian races have, in general, been disinterested in scientific pursuits is to a large extent true—Professor Sarton has aptly divided men into those who understand and practice the experimental method and those who do not—but what has been lacking in the scientific field has been more than compensated for by the great religions, profound philosophies, fascinating literatures, and unique forms in art and architecture, which Asia has presented to .the world as a priceless legacy. Nevertheless, the science of Asia has been seriously underestimated and the West, through the pioneer researches of such men as Sarton, Needham, Ruska, Meyerhof, Carra de Vaux, Wiedemann, and others, is only now coming to realize how little it understands about it.

Conceptions of the Universe held by the people of the Ancient East are to be gained largely through hard study of their vast religious literatures. These people represent, firstly, the River-Valley Cultures of the Nile, Tigris-Euphrates, Indus, and Yellow Rivers, and their picture of the world was usually made to conform to the local geography of their own regions. It would be quite impossible in this brief paper to deal with the details of all their beliefs, but certain salient features are evident. For instance, the “rectangular or square cosmology” became a basis in the East, whereas with the Greeks at a later period the structure of the universe was built upon the circle and the sphere; also Eastern thinkers divided the equatorial belt of the heavens into 28 (or 27) regions corresponding with certain stars and constellations; this division is mentioned in the *Atharva Veda* and the *Taittiriya Brahmaiia* of India, the *Hsia Hsiao Cheng* and the *Chou Li* of China, and in the poetry of Arabia antedating the Qur'an.

C. P. S. Menon has regarded this .scheme based upon the rectangle or square, with its associated numbers such as 4, 12, 28, 60, as a mathematical one, into which the astronomical phenomena were fitted. In a similar way did the Greeks try in their day to make the heavens conform to a system of perfect circles or spheres which involved *%* . The planetary orbits of the Eastern system being rectangular and capable of contraction or expansion in their own planes were thus able to account for the simpler observations, *e.g.,* the positions of the sun at the solstices and equinoxes. Menon thinks that the Egyptian pyramids and the " towers" of Hindu temples may be models of the heavens; no doubt the same might be said of the ziggurats of Babylonia. He writes:—

> There is first of all the earth based on a square, with a corner towards the south, and shaped like a pyramid, with a number of successive homocentric square terraces rising up to 3 point (or rather, to a small square) ; on the top of this is the mount Meru, a pyramid widening out as it rises, at a small angle to the vertical; round this lie the orbits of the sun forming homologous squares on a horizontal plane; above the sun's plane is that of the moon with similar orbits. We may imagine that above this were the planes of the different planets at increasing heights, as described in the Vishnu-purana ; if these were also originally square orbits, we should have the original conception of the orbits of the planets as forming successive terraces of a pyramid representing the heavens. *(Ancient Astronomy and Cosmology, p. 94.)*

The Meru cosmology in the course of time became modified to include circular forms. In the *Suryaprajnapti* of Jaina literature (perhaps of the 5th century B.C.) the mountain of Meru has become the central island in a system of flat concentric rings of land and sea. Whether Greek ideas played any part in this change, or whether indeed both the systems, of the Greeks and the Jains, had a common origin, is one of those controversial questions of priority and transmission which confront us on several occasions in our study of the history of science in Asia, particularly in the mediaeval period, of which we shall speak later. In any case, Homer had a world system in which the hemispherical dome of the heavens (a Chaldean conception) covered the fiat circular disc of the earth around which flowed the great river Okeanos. It is also significant that Jaina philosophy incorporates an atomic theory which recalls that of Demokritos and Leukippos.

Patient observation of the heavenly bodies carried out over long periods of time enabled the priests of these early empires of antiquity to amass a body of reliable astronomical knowledge, since errors were liable to be revealed by the great range of the observations. But science, although the means of determining the calendar (in Egypt as early as 3141 B.C.), was subordinated to religion and to astrology, and it was only with the Greeks that science became divorced and subject solely to impartial inquiry by laymen. The " astronomical" instruments were the clepsydra (or water-clock) to measure time and the sundial (called by the Greeks "gnomon ") to determine angular altitudes. These two instruments with their successors (such as the astrolabe of the Middle Ages) were the sole technical equipment until Galilei, who discovered the isochronism of the simple pendulum and the observational value of the telescope. The workmanship of some of these Asian instruments is a source of pride and wonder. A transit instrument of 1400 B.C. used to determine meridian time in order to set the water-clock is with us today; it was used by Tut'ankh-amun.

Apart from the study of religious literatures, there exist certain writings of a specifically scientific character which the labours of archaeologists have preserved, and which tell us more clearly what was achieved practically. Amongst these are the Egyptian papyri, including the Ahmes Papyrus (c. 2000 B.C.) which gives information on the mathematical processes used by the Egyptians, and the Edwin Smith Papyrus (c. 1700 B.C.) which indicates competent surgical knowledge.

Then there are the earliest records of the practice of science in the Sumerian tablets found at Uruk and dating from *c.* 3500 B.C.; these are followed later by the Babylonian mathematical cuneiform texts of *c.* 1700 B.c. The Babylonian mathematical texts are of two kinds, those dealing with calculation (Table Texts) and those which solve questions ('Problem Texts), and their sequence is suggestive of a modern arithmetical text-book.

Babylonian mathematics is characterized by the principle of position, by which the place-value of a number is used in order to reduce the symbols to a minimum; in effect, this involves an anticipation of the decimal system, but the Babylonian "unit was not 10 but 60 and, when 60 was reached, the symbol for unity was used again but in a different relative position. The so-called sexagesimal system survives today in the measurement of angles and of time.

The Egyptians were less successful in mathematics, for their lack of a principle of position made calculations with high numbers a burden. They excelled, however, in medicine and surgery; acquaintance with anatomy through the embalming of the body and the absence of prejudice against surgical operations laid a valuable foundation upon which Greek medical practice, as Herodotus has mentioned, was largely built. The strength of the mathematics of both the Babylonians and the Egyptians is nicely judged by a consideration of the Theorem of Pythagoras. Whereas the Egyptians never succeeded in finding a relationship between the squares of the sides of a right-angled triangle, the Babylonians did, but it was left to the Greeks to generalize the information in a theorem and to justify it by a deductive proof. So did the Greek genius succeed in passing from individual practical cases to the abstract generalization?

Finally, evidence of the achievements of the Ancient Empires in technology is decisive. The pre-Aryan people of the Indus Valley, who had a flourishing civilization before 3000 B.C., have left clear indications, at Harappa in the Punjab and Mohenjo-Daro in Sind, of dwellings constructed of burnt brick, adequate street drainage, good town-planning and the working of copper and bronze. The Ancient Chinese of the Yellow River Basin were competent irrigation engineers. Engineering achievements of the Nile and Tigris-Euphrates peoples are too well known to require mention here; suffice it to say that on the chemical side also the Egyptians had wrought and cast metals before 3000 B.C., and had the use of a form of chemical beam balance by 2500 B.C., whilst the later Assyrian metallurgical practice at the time of Ashur-bani-pal (7th century B.C.) shows remarkable achievements.

Secondly, following upon these River-Valley Cultures, are the Aryan invaders of India who entered the subcontinent in the 2nd millennium B.C., the Hebrew prophets of the Holy Land, the Zoroastrians of Ancient Iran, the Taoists and the Buddhists, all of whom had something of the scientific outlook.

Whilst the 7th and 6th centuries B.C. were centuries of spiritual awakening amongst men, it should not be forgotten that the realization of one God (monotheism) is in itself a scientific hypothesis, that the Order in Nature expressed in the Way of the Taoist has a striking resemblance to the faith of the modern scientist in Nature’s fundamental laws, and that Buddhism, which applies Causation to the whole Universe, objective and subjective elements alike, is embracing a wider vision of that same law of cause and effect which the scientist modestly confines to objective phenomena which he can weigh and measure.

At this time, when Eastern sages were absorbed in these higher things, the Greeks were confining themselves to this last and material aspect, namely, that Nature could be known in so far as men were prepared to investigate her phenomena objectively, and were instrumental, through the Ionian School of Thales, in laying the first foundations of that cold rationalism which we now accept as science. So the Greeks are called the first true scientists, yet their earliest representatives were frequently under Asian influences, as in the case of Thales himself, who successfully predicted the solar eclipse of 28th May 585 b.c., on the basis of Babylonian data, and Pythagoras whose mystical interpretation of the Universe in terms of numbers is well known. The influence of Greek science is to be traced in the Book of Job. Its materialism impelled St. Paul to flee from the Greek *physis* and seek the salvation of his own soul.

With the Hindus, who had long possessed a great tradition in religious works, beginning with the Vedas, science was still largely subordinate to ritual. Hindu mathematics served the purpose of geometrical design in the construction of the sacrificial altars, as we learn from the supplementary writings to the *Kalpa-sutras*, which are known as the *Sulva-sutras*. Valuable researches into the earlier Hindu and Jaina mathematics have been carried out in recent years by Indian scholars, notably B. Datta and A. N. Singh, and S. R. Das, and are to be found in Indian journals.

Throughout the first millennium before Christ, however, specific scientific and technical achievements were not lacking in the East. We mention the Siloam Tunnel, 1700 feet long, constructed into Jerusalem by order of Hezekiah at the time of the invasion of Sennacherib (726 B.C.) :—

> And the rest of the acts of Hezekiah, and all his might, and how he made a pool, and a conduit, and brought water into the city, are they not written in the book of the Chronicles of the kings of Judah ? *(II Kings*, xx, 20)

Later Babylonian astronomy rivaled that of the Greeks in its accuracy, and Chinese optical knowledge of the fourth century b.c. actually exceeded that of contemporary Greece. For instance, there are passages in the Mohist Canons which indicate that the Chinese understood the pin-hole camera (an invention usually attributed to Ibn Al-Haitham in the early nth century A.D.), the various types of image produced by the concave mirror, and the nature of the principal focus; a little later, during the Han Dynasty, they were producing excellent mirrors of white specular metal which were entirely free from tarnishing. China, which produced the first alchemists around 200 B.C., continued to make valuable technological discoveries, and added one of immense importance in the first year of the Yuan Hsing period (105 A.D.); this was the making of paper from tree bark, hemp, rags, and fish nets by Tsai Lun, an inspector of public works. Pure rag paper dating from 150 A.D. was found in a spur of the Great Wall of China by the famous explorer of Central Asia, Sir Aurel Stein.

We now enter upon a discussion of the medieval period of science, which may be said to begin around 400 A.D. in India, with the *Surya-siddhanta* and the two wonderful metallurgical achievements exemplified in the wrought-iron Pillar of Delhi and the cast-copper colossus of Buddha at Sultanganj; and around 529 A.D. in the Nearer East, with the closing of the schools of Athens by the Emperor Justinian and the dispersal of Greek scientific knowledge, mainly through Nestorian agency, amongst such centers as Antioch, Nisibis, Edessa, and Jundishapur.

This millennium of Asian supremacy in science may be conveniently terminated with the Observatory of Ulugh Beg at Samarkand, which produced the standard astronomical tables of 1437. It is a period exhibiting many features of rare interest; sometimes knowledge passed freely from one end of Asia to the other, sometimes there was utter destruction followed by a revival of patronage as each fresh conqueror built anew; again, there, were brilliant individual researches concentrated in academies which were built, often for a brief life, in each of the great centers of culture as they came to their zenith— Jundishapur, Damascus, Baghdad; C6rdoba and Toledo; Ujjayini and Benares; Maragha, Peking and Samarkand; again, scholars of succeeding generations who might have followed up these researches failed to do so, and against the strength of orthodoxy now crystallized into Scholasticism by such men as Maimonides and Al-Ghazzali, the experimental spirit began to weaken, so that, with the many fluctuations of effort in one country and then another, we cannot now with certainty point to the originators of some of the major discoveries.

Leading authorities disagree on the extent to which Hindu astronomy borrowed from Greece, on the origin of the decimal system, on the science of mediaeval China (undoubtedly much more important than is generally thought), and on the chronology relating to certain Hindu discoveries. It is gratifying to know that there is an increased interest in Europe in the history of science, and this coincides with a revival of pride amongst the Asian countries in their own heritage and cultures. With the opening of many archives, such as the great mosque libraries of Istanbul, and the use of the microfilm copy, which has already been adopted by the Arab League Cultural Committee, may we not hope that the secrets of many more of the precious mediaeval manuscripts or later scribes' copies of them, may be revealed, and that a similar growth of interest in the history of science in Asia (of which we know so little) may in Asia itself also, help us to clarify the many controversial problems which confront us, and which are made harder to European scholars by the barriers of language and script ?

The *Surya-siddhanta* is the most important of five such treatises dealing with mediaeval Hindu astronomy. Though the existing text probably dates from roughly 1000 a.d., Prabodhchandra C. Sengupta writes: —

. . .from 100 to 400 a.d. we have a great gap of 300 years in which astronomical knowledge from Babylonia and Greece came to India. The oldest *Surya-Siddhanta* was transmitted to this country during this period.. . .the earliest date of the *Surya-Siddhanta* cannot be pushed up much higher than 400 a.d., whilst 449 a.d. was the date of our most famous astronomer Aryabhata I. *(Calcutta University Journal of Letters,* xviii, 9-15.)

The standard English version, made by the Rev. E. Burgess " with the aid of Brahmans who were familiar with the Sanskrit and well versed in Hindu astronomical science, " appeared in i860, but a modern edition by Gangooly and Sengupta was produced from the University of Calcutta in 1935. The *Surya-siddhanta* deals with the positions and mean motions of the planets, eclipses and planetary conjunctions, asterisms, the risings and settings of the sun and moon, measuring instruments and astrology. Astrology was a conspicuous feature of all mediaeval thought, East and West, and was quite logical arid consistent with the body of knowledge then existing; in Europe especially it derived ultimately from the *Timaos* of Plato, which advanced the theory of macrocosm (the Universe) and microcosm (Man), wherein events in the former corresponded with and influenced certain reactions in the human being. The geocentric theory, *i.e.*, a central earth with the planets revolving around it, is maintained in the *Surya-siddhanta,* and the moon's distance is given as 51,570 yojanas, which corresponds with the result obtained by the famous Greek astronomer Ptolemy. The prime meridian of longitude was taken through Ujjayini (Avanti), which had long been a centre of Hindu culture and is poetically described in the *Meghaduta* of Kalidasa.

Prior to the first physical synthesis or picture of the Universe in terms of mechanics, due mainly to the investigations of Galilei and of Newton, no satisfactory explanation of the mechanism of the motion of the planets had been advanced; philosophers had been thinking of some agent capable of pushing the planets along, whereas the real mechanism operated at right angles to this and consisted, in Newton's system, of the equating of the opposite centrifugal and gravitational forces. The Hindu explanation in the *Surya-siddhanta* is in no way inferior to that of the *primum mobile* of Aristotle and has some features reminding one of the vortex hypothesis of Descartes.

Forms of Time, of invisible shape, stationed in the zodiac *(bhagana*)> called the conjunction *(cighrocca),* apsis (*mandocca*), and node (*pata*), are causes of the motion of the planets.

The planets, attached to these beings by cords of air, are drawn away by them, with the right and left hand, forward or backward, according to nearness, toward their own place. A wind, moreover, called provector *{pravaha*) impels them toward their own apices (*ucca*); being drawn away forward and backward, they proceed by a varying motion....

Both the *Surya* and *Paulisa Siddhantas* are extremely important in connection with the origin of trigonometry. The Hindus used the sine (jya) and the versed sine (*utkramajya*), and tradition tells us that their trigonometrical knowledge was brought, with a knowledge of the *Siddhantas*, to Baghdad *c.* 770 a.d. by a Hindu pandit named Manka; the Arabs called this astronomical work *Sindhind,* and it was the beginning of a wider and more practical development of trigonometry by later Muslim scholars such as Al-Battani, Abu-1 Wafa', and Nasir AI-Din Al-Tusi, the last-named being the author of an outstanding treatise on spherical trigonometry.

Although the Sassanian period of Persian culture (229-652 a.d.), with the concentration of Nestorian influences upon Jundishapur, coincided roughly with the period of the Gupta Empire in India, towards the end of which the *Surya- siddhanta* was being compiled, and although overland contacts by caravan routes probably led to certain Greek influences in Hindu astronomy, we are in no position to pronounce final judgment on this question. Nevertheless, in respect of the purely trigonometrical ideas we are strongly inclined to credit them as peculiarly Hindu.

The same Hindu genius is undoubtedly to be credited with the development of the decimal system ('although, as we have seen, the Babylonians initiated a principle of position) and with the general adoption of algebraically methods in contrast to the geometrical approach invariably adopted by the Greeks. One particular branch of algebra, namely, the analysis of indeterminate equations, though partly investigated by Diophantus, was so completely worked by both Hindus and Chinese as to become a joint glory. Again the question of priority cannot be clearly answered; but it is purely an Asian achievement, just as in the case of another branch of algebra, the theory of determinants, which the Japanese evolved in elegant fashion in the 17th century from earlier Chinese foundations.

Throughout the mediaeval period, scientific knowledge passed to and fro across Asia. Would that we could go back a thousand years and grow with it; and travel with it along the time-honored trade routes, by camel or by dhow, With the silk or the spices; perhaps to have overheard a learned conversation in a bazar in Bokhara or on a wharf at Hodeida would dispel some illusions. Certain it is that our ignorance of the history of science in mediaeval Asia is profound, especially in respect of China. The transmission of Arabic science, mainly through Sicily and Spain, to Western Europe, is the best understood.

On the passage of Greek science, through the media of the Syriac and Pahlawi languages, to Eastern countries after the fall of Rome, we are much less definite, since the

Nestorian migrations extended even to China. As for Greek astronomical influence upon India, it may have come via any or all of three routes—from Alexandria, the mart of Rome, across the Indian Ocean; from the Near East by way of the Bactrian Kingdoms; from China even, through Nestorian diffusion. Later, in the 6th and 7th centuries A.D., Buddhist pilgrims made the long and arduous journey from China to India in search of the revelation of Gautama and the holy writings, and this at a time when the solution of indeterminate equations was being successfully practiced in both countries and when Hindu members were first being co-opted to a Chinese astronomical board.

Again, we are clearer on the position of Baghdad under the ' Abbasid caliphs, when that famous metropolis at the height of its splendor gathered to itself the science of both East and West; but, alas, since the sacking of the city by Hulagu Khan in 1258, not one in a thousand of the works listed in the great encyclopedia, the *Kitab al-Fihrist* of Al-Nadim, remains! But with loss there is compensation. The Mongols, by their supremacy in Central Asia, kept the caravan routes from Persia to China open for 150 years, so that Muslim influences passed freely eastwards. The beautiful astronomical instruments of Nasir Al- Din Al-Tusi and his collaborators at Maragha, the observatory which flourished in Hulagu's reign, were followed by similar specimens of accurate workmanship in the Peking observatory set up by order of Kublai Khan. To know of these Far Eastern contacts in the world of science, however, we must laboriously translate many more Chinese books over a very long period! But let us return from the realms of nostalgia to the facts we have.

Indeterminate equations have more unknown quantities (which we have to find) than there are actual equations, so that they cannot be solved by the usual methods. One particularly famous problem which occurs in the Chinese treatise Chang Ch'iu-chien Suan-ching, and is usually referred to as the Problem of 100 Fowls, recurs in principle in the *Vija-Ganita* of Bhaskara (*c.* 1150 A.D.). The Chinese version runs: A cock costs 5 pieces of money, a hen 3 pieces, and chickens together 1 piece. If we buy with 100 pieces, 100 fowls in all, what will be their respective numbers? In the Hindu work (*Vija-Ganita,* Chapter VI) it takes this form: Example by ancient authors: 5 doves are to be had for 3 drammas; 7 cranes, for 5; 9 geese, for 7; and 3 peacocks, for 9; bring 100 of these birds for 100 drammas, for the prince's gratification.

The Hindu method of the *Kuttaka* or multiplier made possible integral solutions of the indeterminate equation, $ax \pm by = c$, *i.e.,* whole-number values of x and y which will satisfy the equation when a, b and c have given numerical values. This equation was solved in Europe by Euler in 1770. Brahmagupta, who was flourishing in 628 A,D., tackled the more difficult equation known as the Pellian Equation, the general form of which, $ax^2 + bx + c = y^2$, was completely solved by Bhaskara using his "cyclic method." This general Pellian Equation worried leading European mathematicians in the latter half of the 17th century, and the cyclic method remained unsurpassed until Lagrange in 1769. We may say that in respect of indeterminate equations Hindu and Chinese mathematicians were a thousand years ahead of Europe; unfortunately, higher algebra ceased to arouse much interest in the East after Bhaskara.

Vija-Ganita forms the algebraical portion of Bbaskara's astronomical treatise, *Siddhdnta-siromani.* The arithmetical portion, *Lilawati,* is also of great interest. in connection with the development of numeration and .symbolism, as is another and earlier mediaeval treatise in old Sarada characters. This latter, the Bakhshall Manuscript, consisting of 70 birch-bark folios, was discovered in the extreme north-west of India in May 1881. Much discussion has centred around the date of the Bakhshall Manuscript and also around the question of Hindu priority in the development of the modern decimal system. Arguments favourable and unfavourable have been advanced respecting the latter, but in view of there being some 20 inscriptions in India, dating between 595 A.D. and 1000 a.d., which contain numbers with place-value, and which still require the verdict of expert epigraphists, we cannot state a certain conclusion.

Hindu arithmetic and algebra, in any case, had nothing to learn from Greece and, though Hindu astronomy may have derived certain elements from Greece, the analytical skill of the Hindu algebraists and their interest in numbers make their claim to originality in this instance appear to me to be particularly strong; certainly the Hindu decimal notation and rules were known in China during the period of the T'ang Dynasty (early 8th century A.D.), and this knowledge had a Sanskrit source.

Meanwhile, China continued to develop her technology. Paper was followed by block-printing and movable-type printing, by gunpowder, and by the use of the magnetic compass. The earliest accounts of the practice of block-printing date from about 1000 a.d. Soon afterwards, during the period Ching-Li (1041-1049 A.D.), Pi Sheng, " a man in common cloth " *(i.e.,* of the common people), took sticky clay and cut in it characters as thin as the edge of a copper coin. Each character formed as it were a single type. He baked them in the tire to make them hard. He had previously prepared an iron plate covered with a mixture of pine resin, wax, and paper ashes. When he wished to print, he took an iron frame and set it on the iron plate. In this he placed the type, set close together. When the frame was full, the whole made one solid block of type. He then placed it near the fire to warm it. When the glue was slightly melted, lie took a perfectly smooth board and pressed it over the surface so that the block of type became as even as a whetstone.. ..

In this way, according to the *Meng Chi Bi Tan* (Essays of the Dream Pool), written in the nth century by Shen Kua, did movable-type printing originate.

Gunpowder had been used as early as the 7th century in firework displays, but by the end of the 10th century its propulsive action had been made use of in weapons of war. Metal barrels and bullets became general towards the end of the 13th century, and Europe was forcibly awakened to the potency of firearms by the Mongol invasions of 1235 and 1261.

On the magnetic compass we are less clear. The directive property of a magnetic needle was certainly known and used by the Chinese, but there is evidence to suggest that its navigational value was first realized by the Muslim seamen operating off the China coast, who applied the academic knowledge of the Chinese to a useful end. Be that as it may, the knowledge spread westwards with the Arab dhows, and came to the Mediterranean, where the European mariners were informed. Alexander Neckam (d. 1217) makes the first English reference to it.

The Muslim dominion in medieval times extended its influence into the south of France and into the Saharan oases on the one hand, and on the other it penetrated the heart of Asia and the walls of Cathay. In 711, Muslim armies entered Spain in the West, and Sind in the East. The first great astronomical observatory of the middle Ages (and the first in Europe), the Giralda (now the tower of Seville Cathedral), was a Muslim achievement, as was the last great astronomical observatory of the Middle Ages, that of Ulugh Beg, martyr-prince of the house of Timur-Leng, in distant Samarkand. Nestorian, Persian, Arab and Jewish scholars all contributed to this glorious period of Islam. Baghdad under the 'Abbasids was emulated a century later by C6rdoba under the Umayyad; in the 10th century C6rdoba was "The Jewel of the World," the cultural focus of Europe, where one could walk for 10 miles in a straight line by the light of the public lamps. In London, 700 years later, there was not a single public lamp. Of the mediseval city of One Thousand Nights and a Night little remains save the solitary tomb of Zobeide, favourite wife of Harun-al- Rashld, to remind one of past glories.

But the links in the tradition of science were not broken by the sacking of Baghdad: the long occupation of Spain, 700 years, enabled Muslim, Jew and Christian to affect the passage of the legacy to Latin Christendom. Europe is especially indebted to the broad-minded patronage of Raymond I, Archbishop of Toledo, in the 12th century, and Alfonso X of Le6n and Castile, in the late 13th, who facilitated the translation of Arabic treatises into Latin. Great influence was wielded also by that unusual freethinker of the Middle Ages, Frederick II of Sicily, who founded the University of Naples in 1224 and presented Latin translations to the University of Bologna.

In the transmission of knowledge to Europe the role of the Jewish scholars is of special significance. Many Jewish scholars also made original contributions, as for instance Levi Ben Gerson (1288-1344), a Judeo-Provencal philosopher and mathematician, who invented the cross-staff, an instrument used to measure the angular elevation of the sun. It is instructive to remember that when the last Muslims were leaving Spain in 1492, Columbus was sailing the high seas to America, confident in his belief in a spherical earth derived from an Arabic version of the *Geography* of Ptolemy. 1

Let us note briefly the achievements of three of the most famous Arabic thinkers. I use the term Arabic rather than Arab advisedly, because, although they all flourished under Islam, many Arabic thinkers were Persian. There is such a brilliant galaxy that it is impossible to mention them all; in any case, some were philosophers rather than scientists. We select firstly Ibn Al-Haitham.

Ibn Al-Haitham, known in Europe as Alhazen, was born at Basra in 965 A.D. and died in Cairo in 1039 A*D' Primarily a practical scientist, he ranks as one of the greatest physicists of all time. His studies in optics and his experimental technique undoubtedly influenced Roger Bacon, who has had most of the credit for them. Ibn Al-Haitham made a special study of the nature of light, the camera-obscura, concave and parabolic mirrors, the onset of twilight, and the phenomenon of refraction on which the action of lenses depends. He made his own parabolic mirrors from steel by means of a kind of lathe. He believed that rays of light originated in the luminous source, whereas Euclid and Ptolemy had regarded the human eye as the agency which projected them outwards. He regarded the speed of light as finite but very great.

His application of mathematical methods to the solution of physical problems which arose from his experiments shows that his scientific outlook is that of the 17th century and not of the nth; in particular, he solved the famous problem which perpetuates his name, *i.e.,* to determine the point of reflection on the surface of a concave mirror when the positions of the source of light and the eye of the observer are given : a problem which involved an equation of the 4th degree and necessitated the intersection of a circle with a hyperbola. In his mathematical researches on mirrors Ibn Al-Haitham defined clearly the nature of a principal focus and made considerable progress in the subject of spherical aberration. His knowledge of reflection was superior to that of the Greeks, and in refraction he broke entirely new ground.

This latter achievement is worthy of a further comment:—When a ray of light moving

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1 It is now believed that Columbus may also have heard of a prior discovery oi America by the Portuguese

obliquely in a certain medium (say, air) reaches the surface of separation between it and a second medium (say, water), the direction of the ray is altered and so is its speed. The full implication of these changes brings us into the complexities of contemporary physics, but Ibn Al-Haitham was able to make a convincing explanation of the mechanism of the process, and his statement that the light ray pursues the path which is " the easier and quicker ” brings him near to Fermat's Principle of Least Time. The mathematical relationship which Ibn Al-Haitham might have discovered from his immediate experimental researches on the passage of rays through a glass sphere unfortunately eluded him, despite the fact that sines of angles were fully understood by Muslim mathematicians at that time; the discovery of the true relationship was made in 1621 by Willebrord Snell and is now known to every school-boy as Snell's Law of Refraction.

The work of Ibn Al-Haitham on refraction led to a better theory of the rainbow, a subject which had especially interested Muslim scientists, and this aspect was further investigated by Qutb Al-Dln Al-Shiraz! (1236-1311), a pupil of Nasir Al-Dln Al-Tusi. Europe has preserved the *Optics* of Ibn Al-Haitham (*Kitab Al-Manazir*) in the Latin version printed at Basle in 1572; until recently it was believed that there was no Arabic original extant, but this belief has been dispelled by its discovery in Istanbul and the valuable treatment of Mustafa Nazif Bey based on it. A pupil of Qutb Al-Dln Al-Shirazi, named Kamal Al-Dln Al-FarisI, who died *c.* 1320, made an original commentary on the *Optics* of Ibn Al-Haitham, entitled *Tanqlh Al-Manazir,* and a modern edition of this has appeared in Hyderabad.

Secondly, we have a very famous name, that of 'Umar Khayyam, whose Persian quatrains have had world-wide circulation. It is often forgotten: that he was primarily a mathematician and an astronomer, and the greatest exponent of algebra in mediaeval times. His treatise *Al-jabr wa-l muqabala,* written in Arabic, represents the climax of medieval thought on this subject and is almost,, though not quite, an anticipation of the discovery of co-ordinate geometry made by Descartes in 1637; for it is not an algebraical geometry, but rather a geometrical algebra.

It is mainly concerned with the classification of equations and their illustration or solution by geometrical means. It goes beyond the quadratic equations used by Al-Khuwarizmi (from whose work algebra first came to Europe) and proceeds to an elaborate discussion of the solution of cubic equations by the intersection of the so*called conic sections. We recall that Ibn Al-Haitham solved an equation of the 4th degree by such a procedure. [f] Umar Khayyam systematized the researches of Al-Mahani, Al-Hazin, Al-Quhi, Al- Biruni, Al-Haitham, and Abu-1 Jud, his predecessors in the study of cubic equations, and his treatise serves a useful purpose in revealing to the historian of mathematics the evolution of a phase which is peculiarly Arabic. The *Algebra* of ' Umar Khayyam might have had great influence on Europe had it been transmitted in a mediaeval Latin version. There is no evidence of this, and the known Arabic manuscripts extant have come to light only since the penetration of India by Western races in modern times.

Finally, a few words about Nasir Al-Din Al-Tusi (1201-1274). He was director of the Mongol observatory set up by order of Hulagu Khan at Maragha, some 40 miles south of the modern Tabriz. He is noted for the exquisite workmanship of the instruments made by himself and his staff, who were collected from widely separated cities of the Muslim world, such as Damascus, Mosul, Tiflis, Kazvin. Under Hulagu’s successor Abaqa-Khan, they completed the Ilkhanian astronomical tables. Nasir Al-Din has left a vast output of scientific writings covering a wide field of subjects, including versions of the *Elements* and the *Optics* of Euclid. He was essentially a geometrician and thought very much in terms of the Greek tradition.

Only a passing reference can be made to the chemistry of Jabir ibn Hayyan; the transmission of Greek scientific thought from the Syriac to Arabic due to the great labours of such men as Hunain ibn Ishaq; the mathematics of the *Banu Musa;* the great Arab travellers and geographers; that universal genius Al-Biruni, who wrote so learnedly about India, and was a contemporary of Firdausi at the Court of Mahmud of Ghazna; the valuable medical treatises of Al-Razi (Rhazes) and Ibn Sina (Avicenna); the mechanics of Al- Jazari and of Al-Khazini; and the useful writings on the mechanism and the diseases of the eye. in which the Arabs naturally took considerable interest. Systematic treatises on the Arab horse, as one would also expect, were compiled.

The great scientific revolution of the 16th and 17th centuries in Europe and the subsequent application of scientific principles in the design of technical appliances have obviously influenced Asian science in modern times. We conclude, however, by remarking on four instances which justify native originality. The Hindu Maharaja Sawai Jai Singh II of Jaipur (1636-1743) made an important study of Muslim, Hindu, and European astronomical methods, established observatories at Delhi, Jaipur, Ujjain, Benares and Mathura, improved the technique of measuring instruments, and brought the Samarkand Tables of Ulugh Beg up to date. He was the last great exponent of the traditional Muslim methods which were then passing with the advent of the telescope in Europe. A little earlier, in the latter half of the 17th century, Japanese mathematicians, such as Seki Kowa, had made a unique contribution to higher algebra by their development of the theory of determinants, independently of, and in advance of Europe. In the present century there have been the original mathematical papers of the young Ramanujan and the important researches of Sir Jagadis Bose on the sensitive response of the living plant.

So does the body of scientific knowledge grow by a process of infinitesimal accretion, telling us more and more about the workings of the mysterious universe in which we live, and revealing its secrets by the process of alternate hypothesis and experiment. Hypothesis implies imagination, and the East has always been brilliantly endowed with this faculty. It is revealed both in its poetry and in its mathematics, which are not so widely different as the superficial observer would imagine. One is not therefore surprised to find the glory of Asian science in its mathematical or imaginative aspect rather than in the experimental or practical. He is dull indeed who has not been moved by the fascinating problems of Bhaskara:—

"Beautiful and dear Lilawati, whose eyes are like a fawn’s I Tell me what are the numbers resulting from 135, taken into 12, if thou be skilled in multiplication by whole or by parts, whether by subdivision of form or separation of digits. Tell me, auspicious woman, what is the quotient of the product divided by the same multiplier?” (*Lilawati,* Chapter II.)

“Out of a swarm of bees, V_6 part settled on a blossom of Cadamba ; and $^1/s$ on a flower of Silind'hri : 3 times the difference of those numbers flew to the bloom of a Cutaja. One bee, which remained, hovered and flew about in the air, allured at the same moment by the pleasing fragrance of a Jasmine and a Pandanus Tell me, charming woman, the number of bees. ” (*Lilawati,* Chapter III.)

A few wise words of that imaginative Bhaskara make a fitting conclusion:—

It is apparent to men of clear understanding, that the rule of 3 terms constitutes arithmetic; and sagacity, algebra.. .spotless understanding is algebra.

Notice the ideal created by the imagination, the yearning to understand reality by moving further from the immediate sensual impression into the abstract generalization.